IN THIS ISSUE

Local floras are a particularly useful contribution to our knowledge of the plant life of the Great Lakes region, especially when they cover a well-defined ecological landscape, and even more so when that habitat is under threat. The first article in this issue belongs to that category, providing an account of the flora of the barrens in northwestern Wisconsin. Evaluating eight discrete sites within the barrens region, the authors employ various quantitative and qualitative assessments to compare the sites on a gradient to determine the relative influence of latitude and the surrounding habitats on the flora and its diversity within the barrens region, as well as presenting a complete floristic list keyed to the various sites examined.

Next is another article in the series of studies of the Grand Rapids flora and how it has changed since Emma Cole's 1901 *Grand Rapids Flora*. This entry is an assessment of remnant floodplain habitats that, although they have been drastically impacted by development and other human usages in the area, nevertheless still harbor unique assemblages of native biodiversity. By comparing today's flora of these remnants with the information available to Emma Cole over 120 years ago, the article reviews the changes that have taken place over time and provides important information that will be useful in future preservation and restoration efforts.

The Michigan Botanical Society (then the Michigan Botanical Club) initiated the Michigan Big Tree Program in 1956 that maintains a register of the largest trees of each species in the state. The third article, authored by the current Big Tree coordinator, Ted Reuschel, describes the history of the Big Tree Program, explains its objectives and operations and the criteria used to add individual trees to the register. In addition, the article details how the register may be searched and describes how individuals may contribute to the register, either by nominating individual trees or by acting as volunteer certifiers.

In much of the Midwest, forests are limited to small fragments. Preservation and maintenance of these fragments is essential, and an important basis for this is understanding the diversity and status and their floras and their ecological conditions. The fourth article, which presents a report on ecological and floristic plant surveys of one such fragment, now preserved as the Little Wabash River Nature Preserve in northeastern Indiana, is a contribution to this important effort. Although the property has been subjected to substantial human influence, the authors conclude on the basis of their studies that it is worthy of preservation.

Malcolm MacFarlane's long-term studies of the genus *Botrychium* in northwestern Minnesota (previously reported in Volume 60, pages 82–96, of this journal) have resulted in significant new records for an uncommon species, *B. crenulatum*, reported in a Noteworthy Collections article in this issue.

This is followed by two reviews of new books that each cover a particular group of plants. The first is an updated edition of a classic manual of the aquatic and wetland plants of northeastern North America by Garrett E. Crow, a recent

past president of the Michigan Botanical Society and a long-time student of aquatic plants along with his colleague, C. Barre Hellquist. This work will be a much-needed resource for all those who work with, or who simply enjoy learning about, wetlands and their plant life. The second is another excellent manual of a group of Minnesota plants by Welby R. Smith, the Minnesota state botanist, this time on the ferns and lycophytes. It follows equally excellent earlier books by Smith on the orchids, the trees and shrubs, and the sedges and rushes.

Climate change is widely considered to be a major challenge facing the world, and by many as "the greatest challenge humans have ever faced" (in the words of Bill McKibben). It has also been characterized as an existential crisis facing humankind. More than that, it is also a crisis facing the natural world, with potential severe impacts on and alterations of habitats and posing a threat of extinction to many plants and animals. It is therefore a topic of great interest to all who study nature. The final piece in this issue reviews three books on climate change and is intended to be the first of several reviews covering various aspects of climate change. This first review looks at three books that provide, in different degrees of thoroughness, an overview of the general field of climate change. Future reviews will cover more discrete aspects of climate change, such as the science of climate change, impacts on the physical and natural world, denialism, the effect on plants, social impacts, alternative energy sources, the economics of climate change, and political and policy solutions.

——Michael Huft

THE BARRENS FLORA OF WISCONSIN'S NORTHWEST SANDS ECOLOGICAL LANDSCAPE

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ABSTRACT

The barrens of Wisconsin's Northwest Sands Ecological Landscape are a dynamic mosaic shifting between dry forests and woodlands to open, prairie-like communities depending on the frequency of disturbance. We examined the floristics of eight sites within the barrens that were selected to represent the full latitudinal gradient of the ecological landscape. In the course of this study, we collected 2,213 voucher specimens representing 71 plant families, 217 genera, and 404 taxa. We compared the sites to one another using floristic quality assessments, the Sørensen–Dice similarity index, and various qualitative comparisons. The barrens flora becomes less diverse as you move from the southwest to the northeast. Prairie species are more common and dominant in the southwestern sites, and northern dry forest species are more common and dominant in the northeastern sites.

KEYWORDS: pine barrens, oak barrens, sand prairie, floristics

INTRODUCTION

The diversity of vascular plants in the barrens of Wisconsin's Northwest Sands Ecological Landscape is poorly documented. Natural plant community succession and pine plantations have greatly reduced and fragmented what remains as barrens in this region. Recognizing the importance of this landscape, several management and property master plans were developed by the Wisconsin Department of Natural Resources (2015, 2016, 2017a, 2017b). In a collaborative effort, the Wisconsin Department of Natural Resources hired a Northwest Sand's liaison in 2017 to work with national, state, county, industrial and private landowners to expand the early successional barrens. Documenting the flora of this landscape now is an important step toward creating a base line for future comparisons of vascular plant diversity and for measuring the successes of prescribed management.

The barrens of the Northwest Sands Ecological Landscape are a dynamic mosaic that shift between dry forests and woodlands to open, prairie-like communities depending on the frequency of disturbance. However, ecologically defining the barrens plant community is difficult. The historical records in the Midwest contain several instances of barrens that refer to plant communities that fall somewhere between forest and prairie (Hutchison 1994). Many terms (e.g., sa-

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vanna, brush prairie, oak opening) have been used synonymously with places described as barrens (Heikens and Robertson 1994). Generally, barrens may be described as savanna-like communities dominated by grasses and low-growing shrubs and trees, with scattered larger oaks and pines (Curtis 1959, Wisconsin Department of Natural Resources 2015). Furthermore, these communities tend to be edaphic and to receive periodic disturbances, often in the form of fire (Anderson et al. 1999, Curtis 1959, Hutchison 1994).

While plant communities described as barrens have been documented throughout much of North America (Anderson et al. 1999), this study focuses on those of the Northwest Sands Ecological Landscape in northwestern Wisconsin, which covers approximately 5,066 square kilometers stretching from northwest Polk County to north-central Bayfield County (Figure 1) (Curtis 1959, Radeloff et al. 1998, Wisconsin Department of Natural Resources 2015). Most of the upland soils of this region are comprised of sand, loamy sand, and sand mixed with gravel. This combination results in quick infiltration of water into the ground and produces xeric conditions for the flora of the uplands (Wisconsin Department of Natural Resources 2015).

The barrens flora of the Northwest Sands has been influenced by several environmental and climatic conditions arising from the end of the Pleistocene approximately eleven thousand years ago. At the peak of the Wisconsin glaciation, the survey sites of this study would have been covered with glacial ice (Anderson 2006). As the climate changed and started to warm, species more adapted to the colder climate would have followed the retreating glaciers. Grasslands would have started to migrate northward as broadleaf forest species started moving into the region from the east and south. A dynamic interaction began to form as climate and fires interacted along this prairie and forest border (Anderson 2006). Interspersed between the boreal forest along the Great Lakes to the north, the broadleaf forests to the southeast, and the grasslands and savannas to the southwest were vast open areas of outwash sands, shallow glacial lakes, and tills. It is in this confluence that the Northwest Sands' barrens developed, resulting in the diversity of species that we see today.

Prior to European settlement in the mid-1800s, the Wisconsin barrens, described as pine barrens in the Northwest Sands region by Curtis (1959), would have covered about 930,777 hectares (2.3 million acres). This plant community was concentrated in central, northeastern, and northwestern Wisconsin. Approximately 62%, or 3,141 square km, of the Northwest Sands Ecological Landscape was described as barrens communities (Wisconsin Department of Natural Resources 2015). The land also supported sedge marshes, lowland forests, and upland pine forests. These communities were often maintained by natural and intentional wildfires (Murphy 1931). Today, maybe as little as 20,000 hectares of barrens remain in a fragmented landscape on several county, state, and federally protected public lands (Radeloff et al. 1999).

The Ojibwe are believed to have moved into the area of the Northwest Sands about 400 to 600 years ago (Milwaukee Public Museum 2023; Minnesota Historical Society 2023; Peacock 2022). They likely were using fire at varying intervals to support their communities (Loope and Anderton 1998), thus helping to maintain the openness of this barrens landscape. These intentional fires served

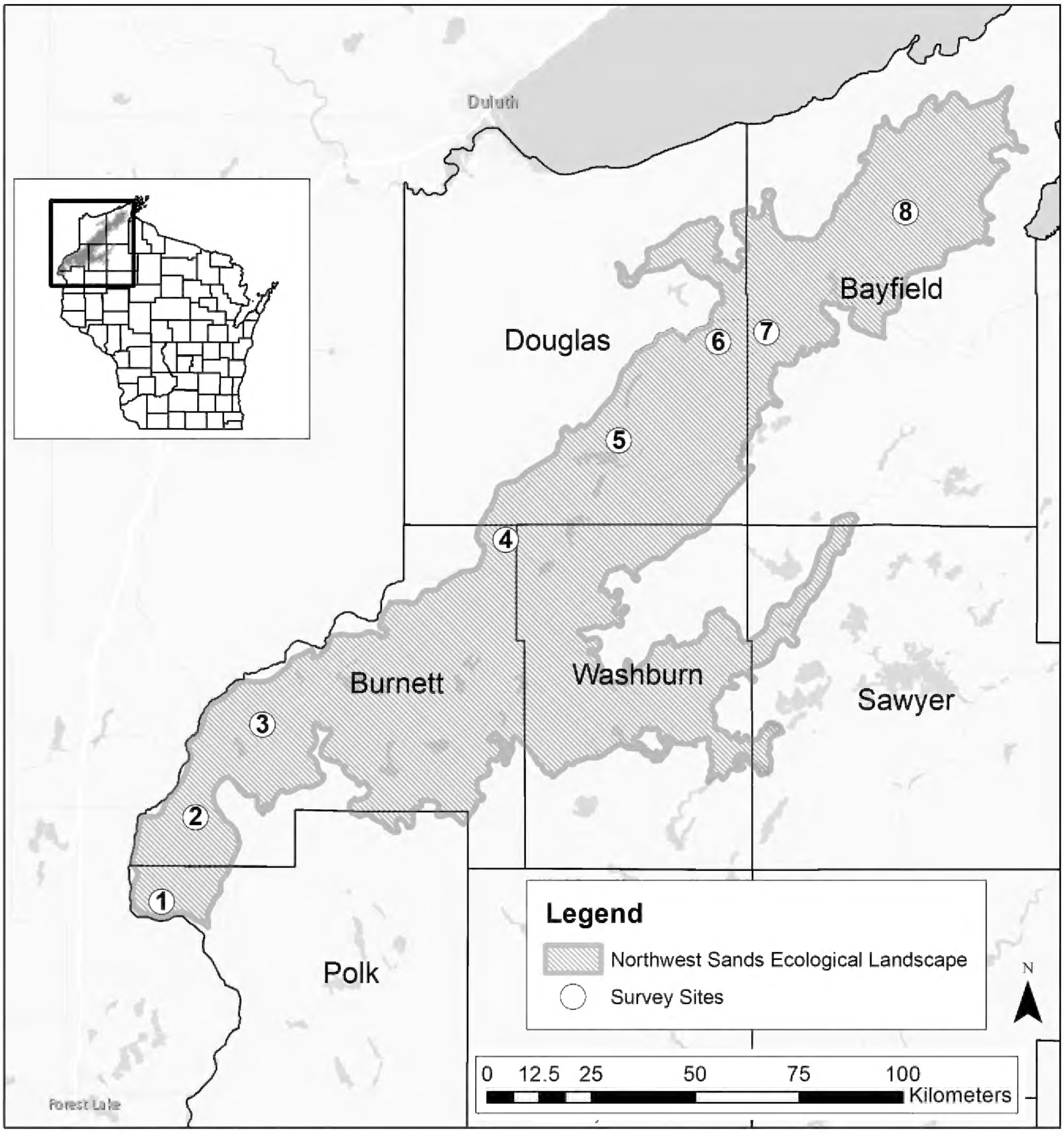

FIGURE 1. The Northwest Sand Ecological Landscape of northwestern Wisconsin, indicated by the hatched area. The specific study sites are indicated by numbered, circled points. (1) Sterling Barrens State Natural Area, (2) Fish Lake Wildlife Area, (3) Crex Meadows Wildlife Area, (4) Namekagon Barrens Wildlife Area, (5) Douglas County Wildlife Area, (6) Motts Ravine State Natural Area, (7) Barnes Barrens, and (8) Moquah Barrens. Inset: location of study area in Wisconsin. The map was created in ESRI ArcGIS 9.3 using publicly available data layers and a shapefile of the Northwest Sands Ecological Landscape provided by the Wisconsin Department of Natural Resources.

many purposes that included regenerating and stimulating the growth of blueberries and other fruits and nuts, clearing brush for campsites and maintaining trails and portages (Anderton 1999; Miller and Davidson-Hunt 2010; Williams 1994). During the mid-1800s, European settlers began draining wetlands and logging the pines. This led to large-scale landscape alteration, fire control, and the disappearance of wildlife, including waterfowl and cranes. Many sites were over-logged, farming was unsuccessfully attempted, and abandoned lands be-

FIGURE 2. Prescribed fire is an important tool used by land managers to maintain the barrens of the Northwest Sands Ecological Landscape. The smoke from a spring fire at Crex Meadows can be seen from miles away. Photo by Richard W. Haug.

came tax delinquent. By the 1940s, the sandy soils were depleted of resources, and nearly two thirds of the land in the region was tax delinquent. The State of Wisconsin, with help from federal financing, began purchasing some of these tax delinquent lands to restore the original uplands and wetlands as public wildlife areas. It was also during this last period that an intensive tree planting and fire suppression program was implemented throughout the landscape. This resulted in closed canopies and forests for industrial uses. By the 1950s, managers were realizing that the early stages of barrens and prairie habitat were dependent on fire at frequent intervals (5–10 years) (Radeloff et al. 2000). As a result of this missing disturbance, the prairie and open barrens were disappearing from the landscape.

The barrens of the Northwest Sands Ecological Landscape include three natural communities described by the Wisconsin Department of Natural Resources (2015). The natural communities are comprised of pine barrens, oak barrens, and sand prairies. These communities form a mosaic on the landscape that grade into one another, making firm distinctions between the community types difficult. The communities are maintained today with frequent prescribed fires by site managers (Figure 2).

The pine barrens community of Wisconsin is savanna-like and usually comprises *Pinus banksiana* (jack pine) and less commonly *P. resinosa* (red pine) at the more northern sites. Shrubby *Quercus ellipsoidalis* (northern pin oak), *Q. macrocarpa* (bur oak), *Corylus americana* (American hazel), *Salix humilis*

(prairie willow), *Prunus pumila* (sand cherry), and *P. virginiana* (chokecherry) are often common. The ground layer is dominated by prairie grasses and forbs (Wisconsin Department of Natural Resources 2022a). This type of pine barrens exists primarily in the upper Midwest, especially in Wisconsin, Michigan and Minnesota. These barrens are considered rare and globally imperiled by NatureServe (2020). Wisconsin has one of the most significant opportunities (and possibly the best opportunity) in North America to preserve, restore, and manage large-scale pine barrens communities (Wisconsin Department of Natural Resources 2017). Other similar barrens communities exist in the northeastern United States, but they are composed of a different assemblage of plant species. They often lack the prairie grasses and forbs that are present in Wisconsin's barrens plant communities.

The oak barrens community of Wisconsin is similar to the pine barrens described above. One observable difference between the two communities is seen in the dominant trees. In the oak barrens community, *Quercus macrocarpa* and *Q. ellipsoidalis* are typically dominant. However, frequent disturbance through fire, poor nutrient levels, and low moisture levels usually leaves these trees stunted, multi-stemmed, and shrubby in appearance (thus they are occasionally referred to as grub oaks). These shrubby oaks often have an extensive root system that is much older than their above ground stems (Johnson et al. 2019). In southern and central Wisconsin, *Q. velutina* (black oak) often replaces *Q. ellipsoidalis* as a dominant oak. An additional difference from the pine barrens community is the presence of a more diverse prairie flora (Wisconsin Department of Natural Resources 2022b).

Sand prairie is the third natural community found in the surveyed sites. These areas typically lack the trees and woody shrubs seen in the pine and oak barrens communities. The sand prairie is dominated by prairie grasses such as *Andropogon gerardii* (big bluestem), *Dichanthelium* spp. (panic grasses), *Hesperostipa spartea* (porcupine grass), *Koeleria macrantha* (June grass), *Schizachyrium scoparium* (little bluestem) and prairie forbs (Wisconsin Department of Natural Resources 2022c). This community is found in the southern sites of our study.

One of our primary goals in this study was a thorough documentation of the flora with voucher specimens that would be accessible to future researchers. Additionally, this comprehensive study allows for site comparisons across the Northwest Sands Ecological Landscape using several different metrics. These data can be used to inform future plant community restoration efforts, invasive species monitoring, rare plant species monitoring and to serve as a point of comparison for future floristic work in the region.

MATERIALS AND METHODS

Survey Sites

We selected eight sites (Figure 1) that span approximately 170 km to represent the barrens found in the Northwest Sands Ecological Landscape. We made site visits to each property throughout the growing seasons of 2017 to 2022. We followed Mladenoff (2004) for the names of the plants found in the Public Land Survey notes included in the site descriptions below.

FIGURE 3. A large area of sand prairie at Sterling Barrens. The prairie is dominated by *Hesperostipa spartea, Andropogon gerardii, Schizachyrium scoparium, Koeleria macrantha, Dichanthelium* spp., *Carex siccata,* and *Carex pensylvanica*. In the foreground *Delphinium carolinianum* subsp. *virescens, Lithospermum caroliniense,* and *Phlox pilosa* are in bloom. In the distance, grub oaks (*Quercus ellipsoidalis* and *Q. macrocarpa*), along with denser stands of *Prunus pensylvanica* and *Amelanchier* spp., can be seen. Photo by Derek S. Anderson.

Sterling Barrens State Natural Area (Polk County, 45° 34.0′ N, 92° 49.0′ W) (Sterling Barrens): Figure 1, Site 1. Wisconsin Department of Natural Resources (2022d)

The Sterling Barrens is the southwesternmost site of our study. It is located in northwest Polk County within the Governor Knowles State Forest approximately 12 km west of Cushing, Wisconsin on moderate to gently rolling slopes of sand outwash above the St. Croix River. While the state natural area includes extensive areas of sedge meadows and floodplain forest near the river, our efforts focused on the upland natural communities of the site. Historically, in the Public Land Survey records, Maddin (1848) describes this area as, "a sand plain covered with small scrubby pine and destitute of water." The site is 398 hectares, of which approximately 100 hectares are barrens (Figure 3).

Fish Lake Wildlife Area (Burnett County, 45° 43.0′ N, 92° 45.0′ W) (Fish Lake): Figure 1, Site 2. Wisconsin Department of Natural Resources (2016, 2022e)

Fish Lake is in southwest Burnett County approximately 8 km southwest of Grantsburg, Wisconsin. The gentle topography of the site is a mosaic of uplands dominated by barrens, while sedge meadows and marshes are characteristic of the lowlands. The landscape was created by an ancient glacial lake that covered most of the area. Our survey efforts focused on the uplands scattered throughout the property. The uplands of this area were described by Fellows (1853a) as, "gently rolling with a foundation of sandy loam soil and very thinly timbered with small pitch pine [*Pinus banksiana*]." The site is approximately 5,666 hectares, of which about 1,214 are barrens.

Crex Meadows Wildlife Area (Burnett County, 45° 51.5′ N, 92° 36.5′ W) (Crex Meadows): Figure 1, Site 3. Wisconsin Department of Natural Resources (2022f)

Crex Meadows is in west-central Burnett County approximately 9 km north-northeast of Grants-

FIGURE 4. *Ceanothus americanus* in bloom in the barrens of Crex Meadows. It is interspersed with other shrubs such as *Corylus americana, Quercus ellipsoidalis* grubs, and *Prunus* spp. *Carex pensylvanica, Andropogon gerardii, Carex siccata, Koeleria macrantha*, and *Dichanthelium* spp. dominate the area between the shrubs. Photo by Richard W. Haug.

burg, Wisconsin. Crex Meadows sits within the same ancient glacial lake basin as Fish Lake (Wisconsin Department of Natural Resources 2016). It consists of gentle topography and is a mosaic of uplands dominated by barrens and woodlands, with lowlands dominated by sedge meadows, marshes and lakes. The landscape today remains similar to what was described by Fellows (1853b) in the public land survey records, where he said, "All of this fractional township except the river bottoms is pine barrens, rolling surface, poor sandy soil, and thinly timbered with pitch pine [*Pinus banksiana*]." The site is approximately 11,533 hectares, of which about 2,833 hectares are barrens (Figure 4).

Namekagon Barrens Wildlife Area (Burnett & Washburn Counties, 46° 7.5′ N, 92° 4.5′ W) (Namekagon Barrens): Figure 1, Site 4. Wisconsin Department of Natural Resources (2017a, 2022g)

The Namekagon Barrens consists of two units located at the junction of Burnett, Douglas, and Washburn Counties approximately 19 km west of Minong, Wisconsin. Both units occur within a matrix of scattered jack pine and, to a lesser extent, red and white pine, which are interspersed with openings in which oak grubs (*Quercus macrocarpa* and *Q. ellipsoidalis*) are prominent, along with prairie grasses and forbs. Historically, the public land survey records describe the general area as having, "a level surface, light sandy soil and thinly timbered with black pine [*Pinus banksiana*]" (Fellows 1855). The north and south units comprise approximately 2,609 hectares of which about 2,183 hectares are barrens.

Douglas County Wildlife Area (Douglas County, 46° 17.0′ N, 91° 50.5′ W) (Douglas County): Figure 1, Site 5. Wisconsin Department of Natural Resources (2017a, 2022h)

The Douglas County Wildlife Area, locally known since 1935 as The Bird Sanctuary, was established in 1948. It is in southern Douglas County west of U.S. Hwy. 53 and between the towns of Solon Springs to the north and Gordon to the south. The sandy uplands of this wildlife area are a result of sandy outwash plains from the retreat of ice during the last glaciation period. Historically

FIGURE 5. Douglas County. The sandy uplands are a result of sandy outwash plains from the retreat of ice during the last glaciation period. The rolling topography as depicted here supports a diverse array of grassland species interspersed with pockets of scrub shrub communities. *Pedicularis canadensis, Antennaria howellii, Packera paupercula, Andropogon gerardii, Bromus kalmii, Schizachyrium scoparium*, and *Koeleria macrantha* are common. Photo by Paul S. Hlina.

these lands supported jack pine, oak savannah, and barrens. Daugherty (1856) does not provide much specific detail, but his description in the public land survey records gives an impression of pine barrens: "the surface of the township is principally rolling land 3rd rate (sandy). Timber black and yellow pine [*Pinus banksiana* and *P. resinosa* respectively], birch, linden, white cedar and spruce." The site is approximately 1,536 hectares of which about 1,451 hectares are barrens (Figure 5).

Motts Ravine State Natural Area (Douglas County 46° 26.0′ N, 91° 36.5′ W) (Motts Ravine): Figure 1, Site 6. Wisconsin Department of Natural Resources (2022i)

Motts Ravine is located about 14 km south-southwest of Brule, Wisconsin on a rolling glacial outwash plain and consists of natural jack pine forest, scrubby Hill's and bur oak thickets, and small pine barrens remnants. The condition of the state natural area is similar to the description of the township by Fellows (1856a): "This is one of those barren townships that is almost worthless for agriculture purposes. The surface is rolling excepting that section adjoining the Brule which is very broken . . . ." The Brule River State Forest manages for this rare community type on the watershed. As noted in the Brule River State Forest Master Plan (Wisconsin Department of Natural Resources 2017b), the extent of Motts Ravine may expand through working with landowners adjacent to the property in the future but is unlikely to be large enough to support significant population of rare plants and animals of the pine barrens ecosystem. Motts Ravine consists of 265 hectares of barrens.

Barnes Barrens (Bayfield County 46° 26.5′ N, 91° 30.5′ W): Figure 1, Site 7. (Bayfield County Forestry Department 2013)

The Barnes Barrens management area is located in Barnes Township in western Bayfield County about 13 km south-southeast of Brule, Wisconsin. Most of the area is dominated by later stages of

FIGURE 6. Barnes Barrens. These are relatively young barrens, having been recently restored and managed (2012–2022) in an extensive sandy outwash plain in western Bayfield County. Most of the area is dominated by *Quercus macrocarpa, Corylus americana, Salix humilis*, and, to a lesser extent, *Q. ellipsoidalis*. Small bands of pine trees remain on the site, but the greatest diversity is found in grass-dominated communities in the western end of the site. Photo by Paul S. Hlina.

the pine barrens community (i.e., mid- to late jack pine forests and oak scrub/pine savanna). Fellows' (1856b) public land survey description of the township provides perspective on the area: "This is a township of barrens that is almost worthless for agricultural purposes or anything else as there is but very little timber in it and that is scrubby black pine [*Pinus banksiana*], and there is hardly a drop of water in the township . . . ." Today, the site is managed by the Bayfield County Forestry Department and is included in Wisconsin's priority conservation opportunity areas for wildlife species. Overall, this matrix of pine forest and late successional-stage barrens communities covers roughly 4,654 hectares. A core area of about 400 hectares of early successional barrens has been created or enhanced in the past decade (Bayfield County Forestry Department 2013). Additional open barrens will be created as harvests occur around this core area. During the duration of this project, we surveyed the 162 hectares being maintained as barrens (Figure 6).

Moquah Barrens (Bayfield County 46° 37.0′ N, 91° 15.5′ W): Figure 1, Site 8. (USDA Forest Service 2004, 2009)

Moquah Barrens is about 35 km southwest of Bayfield, Wisconsin and only 19 km to Ashland and the Chequamegon Bay on Lake Superior (Figure 1, Site 8). Moquah Barrens, which is within the Chequamegon-Nicolet National Forest, was created as glaciers retreated 10,000 years ago exposing rolling to very steep topography of pitted outwash plains consisting of glacial drift (i.e., sand, gravel, and silt). The unique topography of pitted outwash plains, its proximity to Lake Superior and its climatic effects influence plant communities of these barrens. Stuntz (1858) described the township as "high rolling, without any running water in it of a sandy gravelly soil, covered with a scattering growth of black [*Pinus banksiana*], yellow [*Pinus resinosa*] and white pine, aspen, birch and maple." While he does not specifically characterize this area as barrens, his description is representative of

later successional stages of the barrens communities. Today, the Chequamegon-Nicolet National Forest manages the 8903 hectares of the Moquah Barrens.

Field Methods

We conducted multiple floristic surveys at each site each year throughout the growing seasons of 2017 through 2022. We excluded areas from our survey efforts where mature tree cover was visually estimated to be greater than approximately 25%. These areas represented older successional shifts to woodland and dry forests communities that were outside the scope of our definition of early successional barrens. The surveys were restricted to the upland communities of each site. We identified and targeted survey areas by examining aerial imagery available on GoogleEarth, reviewing plant community maps created by the Wisconsin Department of Natural Resources (2015, 2016, 2017a), recommendations from site managers, and from decades of previous experience visiting these sites. Meander surveys were used on site to find microhabitats that may harbor more uncommon species (Goff et al. 1982).

We made specimen collections of any vascular plant species in a reproductive state that had not already been collected on a previous visit to the site as well as specimens needing additional identification in the lab. We also noted species that would need to be collected on a return visit to obtain a more mature specimen. In a few instances, we failed to make those collections. These observations are noted in Appendix 1 with a dagger. Vouchers from each site were deposited at the University of Wisconsin-Madison herbarium (WIS). Any duplicate specimens were submitted to the University of Wisconsin-Stevens Point (UWSP), University of Wisconsin-Superior (SUWS) or the University of Minnesota (MIN).

In addition to our own vouchers, we used the Wisconsin State Herbarium internet portal (Wisconsin State Herbarium 2019) to review past collections made at our survey sites. Species we did not find but had been documented in the past were added to the list in Appendix 1 and cited using the collectors name and collection number.

Species identification and nomenclature follows Voss and Reznicek (2012), or, for several western ranging species at Sterling Barrens State Natural Area, Fish Lake Wildlife Area and Crex Meadows Wildlife that are not included in this regional treatment, Flora of North America Editorial Committee (1993+). Specimen collections from State Natural Areas were made under Wisconsin Department of Natural Resources Permits #SNA18-3 and #SNA20-1.

Floristic Quality Assessment (FQA)

The calculation of FQA metrics is based on the Coefficient of Conservatism (C), which is a numerical rating (0–10) of the fidelity of an individual plant species to specific habitats and its tolerance to disturbance, whether natural or anthropogenic (Swink and Wilhelm 1994). Species that have narrow habitat requirements and/or little tolerance to disturbance (referred to as conservative) are assigned high C-values, while species that are found in more disturbed habitats (tolerant) are assigned low C-values. C-values for species occurring in Wisconsin were assigned by expert botanists from Wisconsin in the early 2000's and assigned for each vascular plant species in the state (Bernthal 2003; Chung-Gibson et al. 2017).

We calculated four metrics of barrens floristic quality using the approach of the Wisconsin Floristic Quality Analysis (Bernthal 2003). Calculations were made for each survey and cumulatively evaluated by barren site. The four metrics are:

1. Mean C_n is the arithmetic average of the C-values of all native plant species observed in a site.

$$\text{Mean } C_n = (C_1 + C_2 + C_3 + \ldots + C_n) / n,$$

Where $C_1, C_2, \ldots C_n$ are the C-values of each of the native species in the site and n is the number of native species in the site.

2. Mean C_t is the arithmetic average of the C-values of all plant species, native and introduced, observed in a site.

$$\text{Mean } C_t = (C_1 + C_2 + C_3 + \ldots + C_t) / t,$$

Where $C_1, C_2, \ldots C_t$ are the C-values of each of the species in the site and t is the number of native and introduced species in the site.

3. Native FQI is calculated by dividing Mean C_n by the square root of the number of native species (n).

$$\text{Native FQI} = \frac{\text{Mean } C_n}{\sqrt{n}}$$

4. Total FQI is calculated by dividing Mean C_t by the square root of the number of all species, native and introduced (t).

$$\text{Total FQI} = \frac{\text{Mean } C_t}{\sqrt{t}}$$

After all calculations were completed, results of native species were compared with total species to illustrate natural versus impacted communities.

Herman et al. (2001) developed an FQI quality scale for natural communities in the state of Michigan. According to this scale, communities with an FQI < 20 have minimal significance for natural quality; those with an FQI between 35 and 50 have sufficient composition for natural quality; and those with an FQI > 50 are highly significant in composition for natural quality and are extremely rare.

Similarity Index

The Sørensen–Dice Coefficient (Dice 1945; Sørensen 1948) is a measure of similarity that was used to compare the floras of each pair among the eight sites included in this study. The Sørensen–Dice Coefficient is calculated as:

$$S = \frac{2c}{(a+b)}$$

where c is the number of species in common between two sites being compared, a is the total number of species from the first site, and b is the total number of species from the second site. The resulting coefficient will range from 0 to 1. The larger the coefficient, the more similar the two sites are to each other.

RESULTS

The barrens flora of the Northwest Sands Ecological Landscape was documented with 2,213 collections representing 71 families, 217 genera and 404 taxa. The largest family was the Asteraceae family with 81 different taxa. The *Solidago* (Figure 7) and *Symphyotrichum* genera were two of the most diverse genera documented in the family, each with ten taxa. Poaceae, Rosaceae, and Fabaceae were the next largest families, with 56, 30, and 22 taxa respectively. Crex Meadows had the highest species richness, with 264 taxa. The site with the lowest species richness was Motts Ravine with 140 species. Douglas County and Moquah Barrens also had a lower species richness with 159 and 157 species respectively. Table 1 compares the total and introduced species at each site. A complete list of species documented in this study is presented in Appendix 1.

We documented 78 new county records of 70 different taxa. Nineteen new records were collected from Polk County, 47 from Burnett County, six from Douglas County, and six from Bayfield County (Table 2).

Several species are nearly ubiquitous across all of the survey sites in the Northwest Sands. Many of these species are common or abundant throughout each site. They are often included in species lists and descriptions for the sites and barrens in the region. Table 3 lists taxa that were observed in at least seven of the eight survey sites. This list includes 12 graminoids, 56 forbs, and 22

FIGURE 7. *Solidago speciosa* is one of the more common goldenrods observed in the barrens. This species, along with *Solidago juncea, S. nemoralis*, and *S. ptarmicoides* are documented at all of the sites we surveyed. Photo by Richard W. Haug.

TABLE 1. The total number of species and the number of introduced species documented at each site. The "% of Flora" is the percentage of the total flora for all sites documented at a particular site. The "% Introduced" is the percentage of species at the site that are introduced.

	Sterling Barrens	Fish Lake	Crex Meadows	Namekagon Barrens	Douglas County	Motts Ravine	Barnes Barrens	Moquah Barrens
Species	218	262	264	191	159	140	172	157
% of Flora	54.0%	64.9%	65.3%	47.3%	39.4%	34.7%	42.6%	38.9%
Introduced	27	36	36	29	34	22	30	24
% Introduced	12.4%	13.7%	13.6%	15.2%	21.4%	15.7%	17.4%	15.3%

shrubs and trees. One species on this list, *Lilium philadelphicum* (wood lily) (Figure 8), is rare and appears to be declining at these sites. Over the last decade, regional State Natural Area staff have seen substantial declines in many forbs, including *L. philadelphicum*. This is thought to be caused in part by increased deer herbivory and a greater reliance on herbicides for management (Magana, personal communication 2023).

Site Findings

Sterling Barrens State Natural Area

While Sterling Barrens is one of the smallest sites surveyed, it is also one of the most diverse. Oak barrens and sand prairie are the dominant plant communi-

TABLE 2. New county records documented in the barrens survey, indicated by an X in the column for the county in which the record was documented.

Species	Polk	Burnett	Douglas	Bayfield
Alyssum alyssoides (L.) L.		X		
Ambrosia psilostachya DC.	X			
Amelanchier interior Nielsen	X			
Amelanchier spicata (Lam.) K. Koch	X			
Antennaria howellii Greene subsp. *canadensis* (Greene) Bayer		X		
Antennaria howellii Greene subsp. *neodioica* (Greene) Bayer	X	X		
Arabis pycnocarpa M. Hopkins	X	X		
Aristida tuberculosa Nutt.	X	X		
Boechera grahamii (Lehm.) Windham & Al-Shehbaz		X		
Botrychium matricariifolium (Döll) A. Braun		X		
Bouteloua curtipendula (Michx.) Torr.	X			
Carex bicknellii Britton		X		
Carex foenea Willd.		X		
Carex muehlenbergii Willd.		X		
Carex richardsonii R.Br.	X			
Carex tonsa (Fernald) E. P. Bicknell var. *tonsa*		X		
Ceanothus americanus L.				X
Ceanothus herbaceus Raf.	X			
Cenchrus longispinus (Hack.) Fernald				X
Daucus carota L.		X		
Dichanthelium columbianum (Scribn.) Freckmann		X		
Dichanthelium depauperatum (Muhl.) Gould	X			
Dichanthelium perlongum (Nash) Freckmann		X		X
Digitaria sanguinalis (L.) Scop.				X
Equisetum laevigatum A.Braun	X			
Euphorbia geyeri Engelm.		X		
Euthamia gymnospermoides Greene	X			
Festuca octoflora Walter		X		
Festuca rubra L.			X	
Froelichia floridana (Nutt.) Moq.		X		
Froelichia gracilis (Hook.) Moq.		X		
Helianthus hirsutus Raf.		X	X	
Hieracium longipilum Torr. ex Hook.			X	
Hypoxis hirsuta (L.) Coville		X		
Kummerowia stipulacea (Maxim.) Makino		X		
Lactuca hirsuta Muhl.			X	X
Liparis loeselii (L.) Rich.		X		
Luzula multiflora (Ehrh.) Lej.		X		
Oenothera clelandii W.Dietr., P.H.Raven & W.L.Wagner		X	X	
Oenothera oakesiana (A.Gray) S.Watson & Coult.		X		
Oenothera perennis L.		X		
Oenothera villosa Thunb.	X			
Oxalis dillenii Jacq.		X		
Packera plattensis (Nutt.) W. A. Weber & A.Löve	X			
Physalis heterophylla Nees.		X		
Polygala polygama Walter	X			
Polygala senega L.		X		
Prenanthes racemosa Michx.		X		
Prunus americana Marshall		X		
Pseudognaphalium obtusifolium (L.) Hilliard & B. L. Burtt			X	X
Rosa arkansana Porter		X		
Rosa woodsii Lindl.		X		

(*Continued on next page*)

TABLE 2. (*Continued*).

Species	Polk	Burnett	Douglas	Bayfield
Sceptridium multifidum (S.G.Gmel.) M.Nishida		X		
Sceptridium rugulosum (W.H.Wagner) Skoda		X		
Scleria triglomerata Michx.		X		
Scrophularia lanceolata Pursh		X		
Setaria faberi R.A.W.Herrm.		X		
Smilax lasioneura Hook.		X		
Solidago altissima L.		X		
Sporobolus cryptandrus (Torr.) A.Gray	X			
Stellaria graminea L.		X		
Symphyotrichum lanceolatum (Willd.) G.L. Nesom var. *lanceolatum*		X		
Symphyotrichum robynsianum (J.Rousseau) Brouillet & Labrecque		X		
Taraxacum erythrospermum Besser	X			
Taraxacum officinale F.H.Wigg.		X		
Tragopogon dubius Scop.		X		
Verbena bracteata Lag. & Rodr.	X			
Vicia cracca L.		X		
Viola pedata L.	X			
Zizia aptera (A.Gray) Fernald		X		

ties. Grub oaks of *Quercus ellipsoidalis* and *Q. macrocarpa* are dominant with occasional scattered *Pinus banksiana*. There are several large open areas of sand prairie, which are dominated by *Andropogon gerardii, Carex pensylvanica, Carex siccata, Danthonia spicata, Dichanthelium* spp., *Schizachyrium scoparium*, and *Sorghastrum nutans*. A number of prairie species were documented only at the Sterling Barrens. These include *Bouteloua curtipendula, B. hirsuta, Packera platensis,* and *Phemeranthus rugospermus*. A few additional prairie species, including *Aristida tuberculosa, Asclepias viridiflora, Dalea villosa,* and *Geum triflorum*, are documented here and Fish Lake.

Fish Lake Wildlife Area

The gentle topography of the Fish Lake area also supported oak barrens and sand prairie, along with small areas of pine barrens where *Pinus banksiana* and *P. resinosa* were more common (Figure 9). The more open sand prairies here are quite similar in composition to those found at the Sterling Barrens. Small populations of *Calamovilfa longifolia* are found here and also at the Sterling Barrens. An interesting observation of the flora of the site were small regions where the only populations of *Botrychium matricariifolium, Botrychium simplex, Hypoxis hirsuta, Prenanthes racemosa,* and *Pycnanthemum virginianum* are documented during our surveys. This site also supported the largest populations of *Hudsonia tomentosa* among all eight sites.

Crex Meadows Wildlife Area

Overall, the barren and prairie plant communities are similar to those at Fish Lake which, as noted above, is situated in the same glacial lake basin. Crex Meadows is one of the largest sites we surveyed. It also contained the highest

TABLE 3. Species documented in at least seven of the eight survey sites, separated into three growth forms. An asterisk indicates an introduced species.

Graminoids	Forbs	Shrubs and Trees
Agrostis scabra	*Achillea millefolium*	*Acer rubrum*
Andropogon gerardii	*Ambrosia artemisiifolia*	*Amelanchier interior*
Aristida basiramea	*Anemone quinquefolia*	*Amelanchier spicata*
Bromus kalmii	*Antennaria howellii*	*Arctostaphylos uva-ursi*
Carex pensylvanica	*Antennaria parlinii*	*Ceanothus herbaceus*
Danthonia spicata	*Apocynum androsaemifolium*	*Comptonia peregrina*
Dichanthelium acuminatum	**Berteroa incana*	*Corylus americana*
**Elymus repens*	*Calystegia spithamaea*	*Diervilla lonicera*
Koeleria macrantha	*Campanula rotundifolia*	*Pinus banksiana*
**Poa compressa*	**Centaurea stoebe*	*Pinus resinosa*
Schizachne purpurascens	*Chamerion angustifolium*	*Populus tremuloides*
Schizachyrium scoparium	*Chenopodium album*	*Prunus pensylvanica*
	Comandra umbellata	*Prunus pumila*
	Conyza canadensis	*Prunus virginiana*
	Crocanthemum bicknellii	*Quercus ellipsoidalis*
	Crocanthemum canadense	*Quercus macrocarpa*
	Erigeron strigosus	*Rosa acicularis*
	**Fallopia convolvulus*	*Rosa blanda*
	Fragaria virginiana	*Rubus flagellaris*
	Helianthus occidentalis	*Rubus idaeus*
	Helianthus pauciflorus	*Salix humilis*
	Heuchera richardsonii	*Vaccinium angustifolium*
	**Hieracium aurantiacum*	
	Hieracium umbellatum	
	Houstonia longifolia	
	Krigia biflora	
	Lechea intermedia	
	Liatris aspera	
	Lilium philadelphicum	
	Lithospermum canescens	
	Maianthemum canadense	
	Maianthemum stellatum	
	**Mollugo verticillata*	
	Monarda fistulosa	
	Oenothera biennis	
	Oenothera oakesiana	
	Packera paupercula	
	Pedicularis canadensis	
	Plantago rugelii	
	Polygala polygama	
	Polygonella articulata	
	**Potentilla argentea*	
	Potentilla norvegica	
	Pseudognaphalium obtusifolium	
	Pteridium aquilinum	
	Rudbeckia hirta	
	**Rumex acetosella*	
	**Silene latifolia*	
	Solidago juncea	
	Solidago nemoralis	
	Solidago ptarmicoides	
	Solidago speciosa	
	Stachys arenicola	
	Symphyotrichum oolentangiense	
	Uvularia sessilifolia	
	**Verbascum thapsus*	

FIGURE 8. *Lilium philadelphicum* is found at all of the surveyed sites with the exception of the Sterling Barrens. While the species has a broad distribution across the Northwest Sands Ecological Landscape, ongoing survey work has seen this species decline at several sites. Photo by Richard W. Haug.

FIGURE 9. The barrens of Fish Lake shows little topography. Much of the site is within the basin of Glacial Lake Grantsburg. In the foreground younger *Betula papyrifera* and *Pinus resinosa* are seen. On the horizon, scattered *Pinus resinosa, P. banksiana, Quercus ellipsoidalis* and *Q. macrocarpa* can be seen. Photo by Derek S. Anderson.

FIGURE 10. Namekagon Barrens. A small grove of about ten, large *Pinus resinosa* trees in the pine barrens is shown to the right. Fire charring of the bark is seen on the lower portion of the trunks. In the background, the area is dominated by grub oaks (*Quercus ellipsoidalis* and *Q. macrocarpa*), *Corylus americana, Comptonia peregrina, Ceanothus herbaceous*, and *Prunus* spp. Common graminoids include *Danthonia spicata, Koeleria macrantha, Schizachyrium scoparium,* and *Carex pensylvanica.* Photo by Derek S. Anderson.

number of taxa documented from any one site. It is at Crex Meadows where *Comptonia peregrina* becomes more common in the barrens landscape, increasing in abundance from here northward. Species found only at this site include *Carex bicknellii, Carex foenea, Erigeron pulchellus, Liatris pycnostachya,* and *Spartina pectinata.*

Namekagon Barrens Wildlife Area

The Namekagon Barrens is a large barrens site found within a matrix of pine plantations and pine and oak forests. Large, scattered *Pinus resinosa* stand tall in the matrix of shrubby *Comptonia peregrina, Corylus americana, Quercus ellipsoidalis*, and *Q. macrocarpa* grubs (Figure 10). It is also evident that many of the prairie species more common to the southwest, such as *Allium stellatum, Amorpha canescens, Dalea candida, Dalea purpurea, Solidago rigida, Symphyotrichum sericeum*, start to disappear before reaching this latitude. Nevertheless, the site does support several species not documented at other sites, including *Polygala senega* and *Rosa woodsii.*

Douglas County Wildlife Area

Pine barrens is the dominant plant community found at the Douglas County site. *Pinus banksiana* and *P. resinosa* are common. The shrub layer consists of

FIGURE 11. The gently rolling topography of Motts Ravine. In the distance, a *Pinus resinosa* plantation is visible. A few lone individuals of *Pinus resinosa* are visible to the right in the photograph. The foreground is dominated by oak grubs (*Quercus ellipsoidalis*). Scattered among the oaks are occasional individuals of *Corylus americana, Comptonia peregrina*, and *Prunus* spp. *Andropogon gerardii, Schizachyrium scoparium, Koeleria macrantha, Danthonia spicata*, and *Carex pensylvanica* make up the common graminoids. Photo by Derek S. Anderson.

oak grubs (*Quercus ellipsoidalis* and *Q. macrocarpa*), *Comptonia peregrina, Corylus americana*, and several species of *Prunus*. It is one of the more disturbed barren sites in our survey. The wildlife area has been a training site for horses and hunting dogs since 1935, which resulted in numerous trails, paths, and other disturbances. It is the site with the highest percentage of its flora made up of introduced species, at 21.4%. This includes large populations of the introduced *Robinia pseudoacacia*. However, this site and the Namekagon Barrens are the only sites in which *Erigeron glabellus* (a western species) is found. *Hieracium longipilum* is observed at this site as a new Douglas County record, expanding its known range farther northward. Also of interest, two grapeferns, *Sceptridium multifidum* and *S. rugulosum*, have been documented at the site. This is also the only site in which *Juniperus communis* was observed.

Motts Ravine State Natural Area

This is the second smallest of the barren sites surveyed, which likely contributes to it having the lowest species diversity among all the sites, with 140 taxa. The area is heavily managed with frequent burns to control tree dominance (Figure 11). Though it is small, many interesting finds were observed here. *Comptonia peregrina, Vaccinium angustifolium, Amelanchier spicata, Prunus pumila*, and *Arctostaphylos uva-ursi* are important small shrub species in these open areas. A healthy suite of grasses and forbs, such as *Andropogon gerardii,*

Bromus kalmii, Liatris aspera, and *Lithospermum* spp. are commonly found here. *Agastache foeniculum, Oenothera clelandii*, and *Froelichia floridana* reach the northernmost limits of their ranges here. The highlight of this site occurred in 2015 during a floral study of the Brule River watershed, when *Lactuca hirsuta* was found, for only the second time in the state (Hlina et al. 2020; Raimond 2021). Mott's Ravine and Barnes Barrens are the only two locations in the Northwest Sands that support small populations of this new state record.

Barnes Barrens

This site was newly created over the last decade (2012–2022) as open barrens. The 162 hectares of the core barren area studied was forested up through 2012. Frequent burns, chemical applications, and mechanical scarification have all been used as management tools at this site. There are several large areas with uniform vegetation of grub oaks of *Quercus macrocarpa*, with a lesser extent of *Quercus ellipsoidalis*, as well as *Corylus americana*, *Salix humilis*, and *Pteridium aquilinum.* Other pockets at this site are quite diverse with notable species including *Lactuca hirsuta, Cynoglossum boreale, Carex houghtoniana, Zizia aptera, Ceanothus americanus, and Carex adusta.*

Moquah Barrens

Moquah Barrens is the largest of the barren sites studied and is heavily influenced by the climate of Lake Superior. It also has the greatest elevation changes among the sites with dry valleys and tall hilltops (Figure 12). *Hudsonia tomentosa* occurs in these barrens only at this site at the windblown hilltops, which are likely part of the old Glacial Lake Duluth shorelines. Many sidehills support a mix of *Quercus* spp., *Corylus americana*, and *Pteridium aquilinum.* Flat areas support extensive grasslands of *Carex pensylvanica, Andropogon gerardii*, *Danthonia spicata*, *Bromus kalmii*, *Schizachyrium scoparium*, and *Avenella flexuosa*. The site contains more northern dry forest species than any of the other sites. These include *Gaultheria procumbens, Maianthemum canadense, Uvularia sessilifolia, Melampyrum lineare, Trientalis borealis, Spiranthes lacera,* and *Prenanthes alba.* Common throughout these barrens in the fall is the striking *Liatris ligulistylis*, which was also found in one small area at Fish Lake. Interestingly, *Liatris aspera* is absent here, but common to abundant at all of the other study sites.

Latitudinal Distribution of Species

As alluded to in the previous section, the ranges of several species are distributed along a latitudinal gradient within the Northwest Sands Ecological Landscape. The northern sites (Moquah Barrens, Barnes Barrens, and Motts Ravine) are more influenced by the northern forests. As a result, several species reach their southern extent here in the Northwest Sands. These include *Agrostis hyemalis, Avenella flexuosa, Carex adusta, Crataegus macrosperma, Cynoglossum boreale, Dichanthelium xanthophysum, Epigaea repens, Geranium bicknellii, Geum fragarioides,* and *Lactuca hirsuta. Arctostaphylos-uva-ursi* (Figure 13), a species that was documented at all of our study sites, has a greater pres-

FIGURE 12. The rolling topography of the Moquah Barrens seen from a hilltop view. Small groves and isolated individuals of *Pinus banksiana* are visible in the distance. Graminoids in the large open swaths between the groves include *Schizachyrium scoparium, Carex pensylvanica, Danthonia spicata*, and occasionally *Avenella flexuosa*. In the foreground, *Solidago speciosa, Liatris ligulistylis, Comptonia peregrina*, and *Prunus pumila* can be seen. Photo by Paul S. Hlina.

ence in the northern sites, where it is sometimes locally dominant. It diminishes in abundance and presence southward to Burnett and Polk Counties.

Similarly, the southern sites (Crex Meadows, Fish Lake, and Sterling Barrens) exhibit a floristic influence from the prairies. Species that approach their northern limits within these barren sites include *Allium stellatum, Ambrosia psilostachya, Amorpha canescens, Artemisia serrata, Aristida tuberculosa, Asclepias viridiflora, Calystegia sepium, Castilleja coccinea, Celastrus scandens, Cirsium discolor, Coreopsis palmata, Dalea candida, D. purpurea, D. villosa, Delphinium carolinianum, Euphorbia corollata, Gaylussacia baccata, Geum triflorum, Hesperostipa spartea, Juniperus virginiana, Liatris cylindracea, L. pycnostachya, Lobelia spicata, Lupinus perennis, Mirabilis alba, Penstemon gracilis, P. grandiflorus, Physalis heterophylla, Phemeranthus rugospermus, Polygonatum biflorum, Ranunculus rhomboideus, Rhus glabra, Scutellaria parvula, Sisyrinchium campestre, Solidago missouriensis, Sporobolus cryptandrus, Symphyotrichum sericeum, Tradescantia occidentalis, Veronicastrum virginicum*, and *Viola sagittata*.

The central sites (Douglas County and Namekagon Barrens) exhibit a con-

FIGURE 13. *Arctostaphylos uva-ursi* grows in large patches in Moquah Barrens, Barnes Barrens, Motts Ravine, and Douglas County and produces large amounts of berries for consumption by birds, mammals, and other wildlife. This circumpolar species reaches the northern latitudes of the arctic, but dwindles in abundance southward through the northwest sand barrens communities. Photo by Paul S. Hlina.

vergence of northern and southern influences. Several species reach their northern limits in the Northwest Sands including *Anemone patens, Artemisia ludoviciana, Asclepias ovalifolia, Boechera grahamii, Cornus foemina, Cycloloma atriplicifolium, Lespedeza capitata, Phlox pilosa, Selaginella rupestris*, and *Solidago rigida*. Northern species reaching their southern limits within these sites include *Capnoides sempervirens, Erigeron glabellus, Hieracium scabrum, Oryzopsis asperifolia, Sibbaldiopsis tridentata, Sisyrinchium montanum, Solidago hispida, Symphoricarpos albus, Symphyotrichum laeve*, and *Turritis glabra*.

Floristic Quality Assessment

Mean C_n values were consistent across all barrens with a range from 4.6 to 4.9 (Table 4). Mean C_t values had a slightly greater range from 3.8 to 4.2 (Table 4). These values of Mean C indicate communities that have a moderate level of

TABLE 4. Floristic Quality Assessment metrics for each of the eight sites.

	Sterling Barrens	Fish Lake	Crex Meadows	Namekagon Barrens	Douglas County	Motts Ravine	Barnes Barrens	Moquah Barrens
Mean C_n	4.7	4.9	4.6	4.8	4.8	4.7	4.8	4.8
Native FQI	64.9	73.2	69.3	61.4	54.0	50.9	57.1	54.8
Mean C_t	4.1	4.2	4.0	4.1	3.8	4.0	4.0	4.0
Total FQI	60.1	68.0	64.5	56.5	47.9	46.7	51.8	50.4

TABLE 5. The number of species at each site that have C-values in each of three ranges of values, 0–3 (tolerant), 4–6 (moderately conservative), and 7–10 (most conservative), and the ratio of tolerant to most conservative species in each site.

	Sterling Barrens	Fish Lake	Crex Meadows	Namekagon Barrens	Douglas County	Motts Ravine	Barnes Barrens	Moquah Barrens
0–3	88	100	108	72	65	53	66	62
4–6	84	104	109	80	68	62	74	65
7–10	46	58	˜47	39	26	25	32	30
Ratio	1.9:1	1.7:1	2.3:1	1.8:1	2.5:1	2.1:1	2.1:1	2.1:1

floristic integrity with a greater amount of habitat tolerant species to habitat conservative species. These values of Mean C_t reflect to some degree the level of introduced plants influencing the quality and suitability of the community.

FQI values indicate a different story about the conditional quality of the barrens. Native FQI values are very high in comparison to other plant community types in Wisconsin. The Native FQI ranges from 50.9 to 73.2, while Total FQI ranges from 46.7 to 68.0 (Table 4). Using the scale in Herman (2001), all the FQI values, whether native or total, reflect communities of high to extremely high natural quality. These high FQI values overall indicate a community with high species richness that forms a matrix of relationships that provide a large suite of habitat needs. These high FQI values also reflect the protected status of all the sites visited. We would expect to see a decline in FQA values on more anthropogenically disturbed sites.

Habitat Tolerant and Conservative Species

Habitat tolerant species can thrive over a wide variety of environmental conditions while adapting to fluctuating levels of resources and nutrients, whereas habitat conservative species exist only in a narrow range of environmental conditions and lower levels of disturbance. A community that has a lower ratio of tolerant to most conservative species is highly susceptible to changing conditions and is under threat of either decreasing or disappearing altogether on the landscape. Table 5 provides a summary of the number of species at each site in the barrens flora that are tolerant to disturbance (C-values between 0 and 3), moderately conservative (C-values between 4 and 6), and most conservative or sensitive (C-values between 7 and 10). The average ratio of tolerant species to most conservative species for all sites was 2.0:1. Fish Lake had the lowest ratio at 1.7:1, while Douglas County had the highest at 2.5:1.

Sørensen–Dice Similarity Index

Calculations of the Sørensen–Dice Similarity Index show a strong similarity between sites that are geographically close to one another. Table 6 compares all of the surveyed sites. The highest similarity between two sites is seen between Fish Lake and Crex Meadows with a coefficient of 0.7833. These two sites are separated by about 20 km. The lowest similarity is found between the Sterling

TABLE 6. Sørensen–Dice Similarity Indices for each pair of the eight barrens sites surveyed in the Northwest Sands Ecological Landscape. Shading of cells in the upper right of the table indicates the degree of similarity. The darker the shading the more similar the two sites are to one another. Values in the lower left of the table are the number of species in common between the two sites.

	Sterling Barrens	Fish Lake	Crex Meadows	Namekagon Barrens	Douglas County	Motts Ravine	Barnes Barrens	Moquah Barrens
Sterling Barrens	X	0.7542	0.7095	0.6161	0.5782	0.4916	0.5333	0.4907
Fish Lake	181	X	0.7833	0.6799	0.6176	0.5224	0.5346	0.5060
Crex Meadows	171	206	X	0.6989	0.6052	0.5347	0.5596	0.5131
Namekagon Barrens	126	154	159	X	0.7429	0.7130	0.7052	0.6379
Douglas County	109	130	128	130	X	0.6890	0.6828	0.6646
Motts Ravine	88	105	108	118	103	X	0.7564	0.6869
Barnes Barrens	104	116	122	128	113	118	X	0.7538
Moquah Barrens	92	106	108	111	105	102	124	X

Barrens and the Moquah Barrens with a coefficient of 0.4907. These two sites are separated by the greatest distance, approximately 165 km.

Rare Species

Several populations of rare plant species tracked by the Natural Heritage Program of the Wisconsin Department of Natural Resources were documented in the course of this study. Eight species (one threatened and seven species of special concern) were observed (Table 7).

TABLE 7. Listing status and S-rank of species in the barrens sites listed by the Wisconsin Department of Natural Resources and the sites in which each occur.

Species	Listing Status	S-Rank	Sites
Asclepias ovalifolia	Threatened	S3	Sterling Barrens, Fish Lake, Crex Meadows, Namekagon Barrens
Coreopsis lanceolata	Special Concern	S2	Moquah Barrens
Dalea villosa	Special Concern	S2	Sterling Barrens, Fish Lake
Packera plattensis	Special Concern	S3	Sterling Barrens
Phemeranthus rugospermus	Special Concern	S3	Sterling Barrens
Sceptridium rugulosum	Special Concern	S2	Namekagon Barrens, Douglas County, Moquah Barrens
Scleria triglomerata	Special Concern	S2	Fish Lake, Crex Meadows
Symphyotrichum robynsianum	Special Concern	S1	Crex Meadows

FIGURE 14. *Asclepias ovalifolia* is the only species found during our surveys that is listed as threatened by the Wisconsin Department of Natural Resources. We found populations at Sterling Barrens, Fish Lake, Crex Meadows, and Namekagon Barrens. The species appears to respond well to management carried out at these sites. Photo by Richard W. Haug.

Asclepias ovalifolia (dwarf milkweed) is a threatened species in Wisconsin (Figure 14). It also appears to be strongly represented at the southern sites of our study. We documented populations at Sterling Barrens, Fish Lake, Crex Meadows and the Namekagon Barrens. Anecdotally, we observed increases in flowering stems and follicle development following prescribed site management (e.g., fire and tree removal). More than ten populations of *Dalea villosa* (silky prairie clover) (Figure 15), are found at Sterling Barrens and Fish Lake. Several of these populations are comprised of hundreds of individuals.

Two other species listed as special concern, *Packera plattensis* (prairie ragwort) and *Phemeranthus rugospermus* (prairie fame flower), were observed only at Sterling Barrens. *Phemeranthus rugospermus* was previously known from the site and continues to persist in these barrens. This is the northernmost known site for the species in Wisconsin. The discovery of *Packera plattensis* also represents a new county record and range extension for the species in the state (Wisconsin Department of Natural Resources 2021a). This is a species more common to the prairies south and west of our survey area. It should be noted that identification of *Packera paupercula* and *P. plattensis* in northwestern Wisconsin is difficult and confounded by the tendency of *P. paupercula* to exist as a tetraploid in the

FIGURE 15. *Dalea villosa* is listed as special concern by the Wisconsin Department of Natural Resources. This western species reaches the eastern edge of its range in western Wisconsin. Many large populations were documented at Sterling Barrens and Fish Lake. Photo by Richard W. Haug.

barrens of this region. It occasionally displays a few characteristics more commonly associated with *P. plattensis* (Mahoney and Kowal 2008; Mahoney, personal communication 2022).

An interesting discovery made at Crex Meadows and Fish Lake was *Scleria triglomerata* (whip nutrush). This species is found in the oak/jack pine barrens of these sites in nearly indiscernible depressions within the barrens landscape. Associates included *Bromus kalmii, Hieracium umbellatum, Juncus* sp., *Lespedeza capitata, Pedicularis canadensis, Solidago* spp., and *Sorghastrum nutans*. We found two populations at Fish Lake and one population at Crex Meadows. *Symphyotrichum robynsianum* (long-leaved aster) was found only at one small location at Crex Meadow in a population consisting of about a dozen individuals. This aster has unusually long leaves and was growing on the edge of a remnant barren stand of jack pine and aspen.

Coreopsis lanceolata (sand coreopsis) was located at Moquah Barrens at the edge of a sandy road in the barrens, possibly an escapee or part of an earlier seeding or restoration activity at the site. *Sceptridium rugulosum* (rugulose grape fern) was located at three sites: Namekagon Barrens in 2020, Douglas County in 1991, and Moquah Barrens in 1929. The latter two specimens were growing in moist sandy soils, one near a relict lake and the other in an open grassy field. The 2020 collection was found in open sandy barrens with flat to gently rolling topography growing in association with *Arctostaphylos uva-ursi, Comptonia peregrina,* and *Rosa* sp.

DISCUSSION

The barren communities of the Northwest Sands Ecological Landscape represent a diverse assemblage of species. Several trends are noted in the distribution of species along the latitudinal gradient of sites from northwestern Polk County in the south to north-central Bayfield County in the north. There is a higher diversity of species in the southwestern sites in comparison to those in the northeast. The barrens of the southern sites are marked with a greater diversity of prairie species, while the barrens of the northern sites tend to have species more characteristic of northern dry forests and woodlands.

Management in the form of fire, robust scarification or tilling, and mechanical chopping, have been critical components in maintaining these sites as early successional barrens. Much of the recent expansion of barrens in the northwest sands is a direct result of two plans, the Wisconsin Sharp-tailed Grouse: A Comprehensive Management and Conservation Strategy (Fandel and Hull 2011) and the Northwest Sands Habitat Corridor Plan (Reetz et al. 2013). Fandel and Hull (2011) discuss the plight of the *Tympanuchus phasianellus* (Sharp-tailed Grouse) in Wisconsin. This is a species of greatest conservation need, and there was a desire to expand and protect high quality barrens habitat in the Northwest Sands. In an earlier study, Gregg (1987) found that fewer than 2000 birds existed in Wisconsin during a census survey of the early 1980s. Gregg (1987) recommended an aggressive landscape habitat management plan for barrens habitat throughout northwestern Wisconsin to prevent extirpation of the Sharp-tailed Grouse from the region. Since 1987, Sharp-tailed Grouse populations have fluctuated, and, in good years, some hunting has resumed. However, recent trends continue to challenge these birds. There was a 26% decrease in populations between 2020 and 2021 in the Northwest Sands, resulting in the cancellation of the hunting season of Sharp-tailed Grouse (Wisconsin Department of Natural Resources 2021b). Only Namekagon Barrens and the new Barnes Barrens have provided some stability and consistency for the Sharp-tailed Grouse.

The second plan, the Northwest Sands Habitat Corridor Plan (Reetz et al. 2013) recommends the creation of corridors to connect the eight sites of our study and other barren properties in the region. The potential habitat corridors, which contain fragmented forests of various growth stages, have been identified to reconnect currently managed barrens properties. These forests can be managed as rotating barrens, which would be made up of large blocks of forest that are harvested and regenerated in a systematic way. These corridors would provide critical habitat for wildlife to move between the larger managed barrens (Reetz et al. 2013). Expansion of this work continues at a rapid pace in Crex Meadows, Fish Lake, Namekagon Barrens, Barnes Barrens and a new area called Bass Lake Barrens that will link Barnes Barrens with Moquah Barrens (Bayfield County Forestry Department 2013; Wisconsin Department of Natural Resources 2015, 2016, 2017a, 2017b; USDA Forest Service 2009).

In the southern sites of our study, the importance of these communities for wildlife is only reinforced. In addition to providing habitat for numerous birds, reptiles, and mammals, the barrens are also habitat for many invertebrates. Perhaps one of the most significant is *Lycaeides melissa samuelis* (Karner blue butterfly).

FIGURE 16. *Lupinus perennis* is documented only at Sterling Barrens, Fish Lake, and Crex Meadows. Many large populations of this species are observed in the oak barrens and sand prairies of these sites. This species is the host plant for the federally endangered Karner Blue Butterfly. Photo by Richard W. Haug.

This federally endangered species is dependent on *Lupinus perennis* (wild lupine), which is commonly found in the southern sites (Figure 16). Maintaining the open savanna-like nature of the barrens is critical for maintaining a strong population of *L. perennis* and its obligate companion, the Karner blue butterfly.

In the northern sites, graminoids, oak scrub, and other woody shrubs continue to be the dominant features in the barrens. Anecdotally, these recent observations in tandem with over 20 years of visiting these sites, suggests a decline in some flowering forbs, such as *Asclepias tuberosa, Rudbeckia hirta, Lilium philadelphicum, Liatris aspera, Monarda fistulosa* and *Monarda punctata*. Future vegetative studies and observations could provide quantitative results of the changing landscape. If our suspicions are correct, these future studies would show that the barrens is experiencing a greater biotic homogenization while diminishing habitat values for insects, pollinators, birds and wildlife, as has been shown in other forest and non-forested ecosystems in Wisconsin. Future work could examine some further causes of habitat challenges in the barrens that may include deer herbivory, habitat fragmentation, management practices or lack thereof, a warming climate, anthropogenic disturbance, and mismatches in the synchronous relationship between flowering plants and pollinators.

Deer herbivory poses a serious threat to the proper functioning of these barrens ecosystems of the Northwest Sands Ecological Landscape. One of the first Wisconsin studies on the impact of deer was conducted by Alverson et. al. (1988). This study illustrated the negative impact of elevated *Odocoileus vir-*

ginianus (white-tailed deer) populations on the vegetation of northern Wisconsin. Over the ensuing 30 plus years the deer problem has intensified. Rooney (2009) describes the simplification and biotic homogenization of northern natural landscapes due to high deer densities browsing on forbs and woody vegetation in forested landscapes, which in turn favor graminoid species.

The increase in deer pressure on the vegetation coupled with decades-long changes in disturbance patterns (primarily fire suppression) may be related to an increase in the presence of *Carex pensylvanica* in the barrens. This species is normally considered a species of dry forests, but now is seen to be abundant in many areas of the barrens. In a floristic study conducted by Thomson (1945) in the barrens of the Brule River watershed, more than 127 species were documented, although *Carex pensylvanica* was not noted. Additionally, the work of Curtis (1959) lacks the inclusion of *C. pensylvanica* as a dominant, co-dominant, or associate species on his lists for pine barrens communities. In examining the northern sites of this study, we observed areas where monoculture stands of *C. pensylvanica* had formed. These dense pockets provide little opportunity for the establishment of other barrens species (Abrams et al. 1985). Long-term, this condition could further the degradation of sites, thereby reducing the diversity of plant species.

CONCLUSION

Our documentation of the flora of the region will provide data that adds to the vast body of knowledge of the region. The floristic quality assessments can serve as a baseline in strategic management plans (Magurran et al. 2010). They can be used to re-evaluate the flora at regular intervals in the future (e.g., once every 5 to 10 years). Lower values may indicate some changes in the environmental conditions on the sites that could influence future management decisions to maintain or increase floristic quality. Surveying after the implementation of management strategies would be highly beneficial to document the resurgence and expansion of barrens species that may be dormant or in the seed bank. Additionally, these surveys should target rare species listed by the state. It will be beneficial to document their responses to management and incorporate this information into conservation efforts in the future.

The expansion of the barrens on the landscape will allow plant populations to expand their narrow ranges of present day. It appears that there is a suite of plants (e.g., *Allium stellatum*, *Asclepias ovalifolia*, and others) that may lay dormant in the shaded forest of the region that will be expressed once trees are harvested. As continued restoration activities proceed throughout the Northwest Sands Ecological Landscape, future floristic studies will continue to expand our understandings of these ecosystems.

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APPENDIX 1. List of species found at the barrens sites. The list is organized by major plant group (pteridophytes and lycophytes, gymnosperms, dicots, and monocots), then alphabetically by family, genus, and species. An asterisk indicates an introduced species. The collection numbers that follow each species name indicate the lead collector by a prefix: A = Anderson; F = Feist; H = Hlina; Hg = Haug; M = Marcum; P = Phillippe; and W = Wetter. Nomenclature follows Voss and Reznicek (2012) or, for several western ranging species not included in that work, Flora of North America (1993+). The survey sites are denoted by the following column headers: S = Sterling Barrens; F = Fish Lake; C = Crex Meadows; N = Namekagon Barrens; D = Douglas County; Mt = Motts Ravine; B = Barnes Barrens; and Mq = Moquah Barrens. A qualitative abundance estimate is given for each taxon at each site at which it occurs with a letter representation as follows: A = Abundant (plants are dominant and found throughout much of the site); C = Common (plants are found in high numbers but may be patchy or dominant in local patches); O = Occasional (plants are sporadic at the site and mostly present as scattered individuals); and R = Rare (only a few plants observed, or local and restricted to small areas of the site). A dagger (†) superscript on these codes is used to denote an observed species that we failed to document with a specimen.

Taxon	S	F	C	N	D	Mt	B	Mq
PTERIDOPHYTES AND LYCOPHYTES								
DENNSTAEDTIACEAE								
Pteridium aquilinum (L.) Kuhn (bracken fern); A3219, A3252, A3304, A3491, F7455, H6248, H6290, H6697, W1507	C	C	C	A	C	C	A	C
EQUISETACEAE								
Equisetum hyemale L. (scouring rush); H-53			R					
Equisetum laevigatum A.Braun (smooth scouring rush); A3213, H5005	R		R					
Equisetum ×ferrissii Clute (Ferriss' horsetail); A3576, Hg305		O	R					
LYCOPODIACEAE								
Dendrolycopodium hickeyi (W.H.Wagner, Beitel & R.C.Moran) A.Haines (Hickey's clubmoss); H4992, H6832								R
Diphasiastrum digitatum (A.Braun) Holub (southern ground cedar); H5442, H6053, H6661, H7056				R			R	R
Lycopodium clavatum L. (running club-moss); A3311, H5383							R	
OPHIOGLOSSACEAE								
Botrychium matricariifolium (Döll) A. Braun (matricary grape fern); A2782		R						
Botrychium simplex E. Hitchc. (least moonwort); A2760, A2783		R						
Botrychium tenebrosum A.A. Eaton (shade moonwort); A3089		R						
Sceptridium dissectum (Spreng.) Lyon (cut-leaved grape fern); H6083, H6107								R
Sceptridium multifidum (S.G.Gmel.) M.Nishida (leather-leaf grape fern); A2958, A2971, A2978, A2981, A3739, H151, H5433, H5452, W1541	R	R	R	O	R			
Sceptridium rugulosum (W.H.Wagner) Skoda (rugulose grape fern); A3342, Brakke (s.n.), Wilson (1712)				R	R			R

(*Continued on next page*)

APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
SELAGINELLACEAE								
Selaginella rupestris (L.) Spring (dwarf spike moss); A2897, A2974, A2983, A3046, A4084, F7151, H4722, W1582	O	O	O	O	R			
GYMNOSPERMS								
CUPRESSACEAE								
Juniperus communis L. var. *depressa* Pursh (common juniper); H5064					R			
Juniperus virginiana L. (eastern red cedar); A2947	O							
PINACEAE								
Abies balsamea (L.) Mill. (balsam fir); H5437							R	
Pinus banksiana Lamb. (jack pine); A2952, A2955, A2963, A2966, A2975, A4076, F7039, H4581, H6047, H6165, H6619, M6691	C	C	C	C	C	C	C	C
Pinus resinosa Aiton (red pine); A2982, A3290, A3562, F7051, H6052, H6620, P43916		O	O	O	O	O	O	O
Pinus strobus L. (white pine); A2965, H4600, H6051, H6286, H6562		R	O		O	O	O	
DICOTS								
AMARANTHACEAE								
Chenopodium album L. (lamb's quarters); A3555, A3575, H4568, H6375, H6577, H6589	R	R	R†	C	O	R†	R	R†
Chenopodium pratericola Rydb. (desert goosefoot); M7449		R						
Chenopodium simplex (Torr.) Raf. (maple-leaved goosefoot); A4345	R							
Cycloloma atriplicifolium (Spreng.) J.M.Coult. (winged pigweed); A3379, H6373			R	R				
Froelichia floridana (Nutt.) Moq. (common cotton-weed); H6299, H152, H6486, H6486, W1481		R	R	R		R		
* *Froelichia gracilis* (Hook.) Moq. (cotton-weed); A2793, A3574, A4247, H5821, H6388, H6615	O	O	O	R				
ANACARDIACEAE								
Rhus glabra L. (smooth sumac); A3242, A3612, A4181, F7426, F7477, H7019	C	C	C					
Rhus typhina L. (staghorn sumac); H4168, H4548, H5021			O					
Toxicodendron rydbergii (Rydb.) Greene (western poison ivy); A3153, A3688, A3506, A3567	O	O	O		R†			R†
APIACEAE								
* *Daucus carota* L. (Queen Anne's Lace); H5749			R					
Zizia aptera (A.Gray) Fernald (heart-leaved golden alexanders); A3064, A3138, A3483, A3622, A4249, H4904, H6859		O	R	R			R	

APOCYNACEAE								
Apocynum androsaemifolium L. (spreading dogbane); A3181, A3258, A3315, A4100, H4046, H4236, H4381, H4425, H4652	O	O	O	O	C	C	C	C
Apocynum cannabinum L. (Indian hemp); A4118, F7144, F7158, H4537, H5060	R	R	R		R			
Asclepias exaltata L. (poke milkweed); H4491				R				
Asclepias ovalifolia Decne.(dwarf milkweed); A2754, A3146, A4051, A4060, A4177, F7181, F7238, F7472, H4227, H4246, H4378, H4476, H4531	R	O	O	R				
Asclepias syriaca L. (common milkweed); A3247, F7479, H4458, H6380, H6586, M7437	O	O	O	O			R	
Asclepias tuberosa L. (butterfly milkweed); A2941, A3139, A3221, F7232, F7424, H4218, H4369, H5327, H5649, H6340, W1489	O	O	O	C	O			
Asclepias viridiflora Raf. (green-flowered milkweed); A2903, H3100	O	R						
AQUIFOLIACEAE								
Ilex verticillata (L.) A. Gray (winterberry); A4416, F7157	R	R						
ARALIACEAE								
Aralia hispida Vent. (bristly sarsaparilla); A3566, H5048, Bruederle (s.n.)			R				R	R
ASTERACEAE								
Achillea millefolium L. (common yarrow); A3226, F7169, F7436, H4352, H4385, H4430, H5634, H6272, H6292, M7454,	O	O	O	C	C	O	C	O
Ambrosia artemisiifolia L. (common ragweed); A2915, A3397, F7429, H4061, H4547, H4550, H4619, H6326, H6389, H7057, W1497	O	O	O	C	O	R		R
Ambrosia psilostachya DC. (western ragweed); A2899, A4236, F7399, H4692, H4724, M7439, W1579	O	O	O	R				
Anaphalis margaritacea (L.) Benth. (pearly everlasting); A3309, A3387, H6579			R				O	O†
Antennaria howellii Greene subsp. *canadensis* (Greene) Bayer (Canadian pussy-toes); A3057, H5453		O			R			
Antennaria howellii Greene subsp. *neodioica* (Greene) Bayer (field pussy-toes); A3055, A3059, A3072, H4956, H5801, H6089, H6287	R	O	O		O	O	R†	O
Antennaria howellii Greene subsp. *petaloidea* (Fernald) Bayer (small pussy-toes); A3032, A3053			O					
Antennaria neglecta Greene (cat's-foot); A3015, A3485, H4358, H4394, H4755, H4786, H4821, H4881, H4882, H5266		R	R	R	R		R	R
Antennaria parlinii Fernald (Parlin's pussy-toes); A3025, A3054, A3061, A3498, A3876, H4343, H4395, H4753, H4783, H4585, H4820, H4889, H4961, H5251, H6091, M6693	R	O	O	C	C	C	C	C
Artemisia campestris L. subsp. *caudata* (Michx.) Hall & Clements (field sagewort); A2894, F7395, H5204, H6328, W1482	C	C	C	O	C			
Artemisia ludoviciana Nutt. (prairie sage); A2933, F7423, H4508, H5206, W1486	O	O	O	C				
Artemisia serrata Nutt. (saw-tooth wormwood); A2928	R							

(*Continued on next page*)

APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
* *Centaurea stoebe* L. subsp. *micranthos* (Gugler) Hayek (spotted knapweed); A3212, A3696, F7400, H4088, H4450, H6255, H6316, H6343, H6360, W1495	O	O	O	C	C	O	O	O
* *Cirsium arvense* (L.) Scop. (Canada thistle); H6603, H6861						O	R	
Cirsium discolor (Willd.) Spreng. (field thistle); A3632, A3741	R	R						
* *Cirsium vulgare* (Savi) Ten. (bull thistle); A3601	R						R†	
Conyza canadensis (L.) Cronq. (horseweed); A2896, A3275, F7439, H6267, H6361, H6561, P43898	O	O†	O	C	O	O	O	O
Coreopsis lanceolata L. (lance-leaf tickseed); H4989								R
Coreopsis palmata Nutt. (prairie tickseed); A2909, A3260, A4255, F7454, H3099, H4448	O	R	R					
* *Crepis tectorum* L. (hawk's beard); A3175, A4094, F7155, H4191, H4721, H4991, H5624, H5630	O	O		C	O		O	O
Erechtites hieraciifolius (L.) DC. (American burnweed); H4196, H4269, H4635, H4667, H6595			R	R		R	R	
Erigeron glabellus Nutt. (streamside fleabane); A4233, A4248, H4189, H4479, H4498, H5202, H5757, H6318, H6393, H7199, Vogl (1962)			R	O	R			
Erigeron philadelphicus L. (marsh fleabane); A3517		R						
Erigeron pulchellus Michx. (Robin's plantain); Hg763			R					
Erigeron strigosus Willd. (daisy fleabane); A2895, A3296, A3316, A4054, F7435, H4416, H4576, H4591, H4993, H5947, M6746, W1496, W1533	C	C	C	A	A	O	C	O
Eurybia macrophylla (L.) Cass. (big-leaved aster); H5940, H6353, H6655				R			R	O
Euthamia graminifolia (L.) Nutt. (flat-topped goldenrod); A2939, A3372, A3398, F7481, H5191, H6834, P43906, W1570	R	O	O			O	O	R
Euthamia gymnospermoides Greene (Great Plains flat-topped goldenrod); A3373, A3406	O	O						
Helianthus giganteus L. (giant sunflower); A3255, H4604, H5285, H5842, W1498		O	O					O
Helianthus hirsutus Raf. (hairy sunflower); H5761, H5939, H6601				R		R		
Helianthus occidentalis Riddell (few-leaved sunflower); A2902, A4254, F7422, H4213, H4636, H5194, H6551, M6745, W1480	C	C	C	A	C	C	C	O†
Helianthus pauciflorus Nutt. (stiff sunflower); A2910, A3713, H4534, H5192, H5205, H6552, H6605	O	C†	C	C	O	O	O	
Helianthus petiolaris Nutt. (plains sunflower); A3635		O						
Helianthus strumosus L. (woodland sunflower); A4235, A4235, H4271			R	R			R	
Heliopsis helianthoides (L.) Sweet (false sunflower); A3217, H5750, H5828	R		R					R
* *Hieracium aurantiacum* L. (devil's paintbrush); A3131, A3293, A3313, F7167, F7206, H4389, H4417, H5629, H6831, P43897		O	O	C	O	O	O	O
* *Hieracium caespitosum* Dumort. (yellow king-devil); A3310, H4099, H4590, H4959, H5636, M6743					O	O	O	O
Hieracium longipilum Hook. (hairy hawkweed); A3349, H3096, H4211, H4212, H4223, H4536, H6556, M7448		R	R		R			

* *Hieracium piloselloides* Vill. (glaucous king-devil); H4387, H4426, H4473, H6348, H6830, H6391				O	R	O	O†	O
Hieracium scabrum Michx. (rough hawkweed); A3325, A3624, H4198, H5058, H5196, H6585, H5824, H6266, H6835, P43891, P43907			R	O		R	O	O
Hieracium umbellatum L. (narrow-leaved hawkweed); A2905, A3294, A3308, A3350, A3360, A4349, H4268, H4471, H4500, H4519, H5526, H4566, H4597, H5759, H6291	R	R	O	C	O	O	O	O
Krigia biflora (Walter) S. F. Blake (false-dandelion); A3560, A4077, A4098, F7172, F7217, H4102, H4427, H4999, H5043, H6874, H6878, H6892		O	O	O	O	O	R	R
Lactuca canadensis L. (Canada lettuce); A3224, A3326, A3623, A3633, A4174, H4467, H5197, H5839, H6092, H6263, H7136, P43854	R	R	R			O	O	O
Lactuca hirsuta Nutt. (hairy lettuce); H6261, H6410, H6412, M6749						O	O	
* *Lactuca serriola* L. (prickly lettuce); H5052, H5837							O	
* *Leucanthemum vulgare* Lam. (ox-eye daisy); A4096, H4435, H5638, H6864, H6881, H6893					O	O	O	O
Liatris aspera Michx. (rough blazing-star); A2900, A3300, A4238, F7394, H4210, H4563, H4564, H5953, H6582, H6600, H7209, P43904, W1491	A	A	O	A	C	O	C	
Liatris cylindracea Michx. (few-headed blazing-star); A3600, A4253, A4261, H3087	R	R	R					
Liatris ligulistylis (A.Nelson) K.Schum. (northern plains blazing-star); A3281, A3694, H4517, H5250, H5255, H7058		R						C
Liatris pycnostachya Michx. (prairie blazing-star); H5239			R					
Packera paupercula (Michx.) Á.Löve & D.Löve var. *paupercula* complex (balsam groundsel); A3088, A3510, A3918, A4062, F7175, H4356, H4383, H4574, H4897, H4953, H4990, H5033, H5611, H5627, H5641, H6899, H7202		O	O	C	R	R	O	O
Packera plattensis (Nutt.) W. A. Weber & A.Löve (prairie groundsel); A2867	R							
Prenanthes alba L. (white rattlesnake-root); A3362, H4527, H4603, H5256, H5944		O	O	O				O
Prenanthes racemosa Michx. (purple rattlesnake-root); A3737, Hg395		R						
Pseudognaphalium macounii (Greene) Kartesz (clammy cudweed); A3289, A3301, A3332, H5045							R	R
Pseudognaphalium obtusifolium (L.) Hilliard & B. L. Burtt (fragrant cudweed); A2881, A3239, A3254, A3396, A4434, H4190, H4632, H5264, H5265, H5948, H6250, H6566, P43919	O	O	O	O	O	R	O	
Rudbeckia hirta L. (black-eyed Susan); A3222, H4431, H4440, H5748, H5762, H6341, M7450	O	O	O	C	O		R†	R
Solidago altissima L. (late goldenrod); A3388, A3407, A3710, H4731, H5270, H5275, H6406, H6565, W1542	O	O	O	O	O		R	
Solidago canadensis L. (Canada goldenrod); H6357, H6593							O	O
Solidago gigantea Aiton (giant goldenrod); A2940, A4344, H22, H4562, H6350, M7461	O	O	O		R			R
Solidago hispida Willd. (hairy goldenrod); A3334, H4512, H4526, H6376, H6405, H4657, H6574, P43910			R†	O	O	O	O	C

(*Continued on next page*)

APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
Solidago juncea Aiton (early goldenrod); A2906, A3273, A3299, A4237, A4195, H4468, H4477, H4518, H4660, H5193, H5269, H6315, H4617, P43895	O	O†	O	A	O	O	O	O
Solidago missouriensis Nutt. (Missouri goldenrod); A2898, F7431, W1518	O	O	O					
Solidago nemoralis Aiton (gray goldenrod); A2893, A3331, A4431, F7403, H4184, H4239, H4520, H4571, H4595, H4625, H4648, H5279, M7460, P43894	C	C	C	A	C	C	C	C
Solidago ptarmicoides (Torr. & A.Gray) B.Boivin (upland white goldenrod); A3298, A3333, A3602, F7440, H4094, H4558, H4735, H5293, W1534	R	O	O	C	O	O	R†	R†
Solidago rigida L. (rigid goldenrod); A2914, F7421, H5277, W1531	R	R	R					
Solidago speciosa Nutt. (showy goldenrod); A2814, A2890, A2908, A3282, A3283, A4180, A4430, F7412, H3092, H4202, H4469, H4510, H4557, H4594, H4624, H4651, H4665, H4733, H5037, H5208,	C	C	C	C	O	O	C†	O
Symphyotrichum ciliolatum (Lindl.) A.Löve & D.Löve (Lindley's aster); H5292, H6614, H4650, H5260, H5268, H6572, H7048			R	O		O	O	C
Symphyotrichum laeve (L.) A.Löve & D.Löve (smooth aster); A3328, A4234, H4422, H4465, H4516, H4560, H4583, H5038, H6265, M6740, P43912				O	R	O	O	C
Symphyotrichum lanceolatum (Willd.) G.L. Nesom var. *hesperium* (lined aster); A3364, A3366, A3374, A3742, H4629, H4736, H4737, H5273, H5274, H5286, H7138	R	R	R				R	
Symphyotrichum lanceolatum (Willd.) G.L. Nesom var. *lanceolatum* (lined aster); H4188, H4266, H6563, H6584			R	O	R		R	
Symphyotrichum oolentangiense (Riddell) G.L.Nesom (azure aster); A2911, A3712, A3770, A4412, A4433, F7465, H4186, H4238, H4472, H4492, H4565, H4616, H4626, H4664, H4723, H5188, H5198, H5199, H5272, H6573, H5827, M7444, P43889, W1539	*A*	*A*	*A*	*C*	*A*	*A*	*A*	*C*
Symphyotrichum pilosum (Willd.) G.L.Nesom (awl aster); H4631, H5267, H6583			R				R	
Symphyotrichum praealtum (Poir.) G.L.Nesom (veiny lined aster); F7474			R					
Symphyotrichum robynsianum (J.Rousseau) Brouillet & Labrecque (Robyn's aster); A2820, F7474.1, Hg167, Hg168, Hg169			R					
Symphyotrichum sericeum (Vent.) G.L.Nesom (silky aster); A2936, A3740, A4415, F7444, H4630, H5278, H3091	R	R	R					
Symphyotrichum urophyllum (DC.) G.L.Nesom (arrow-leaved aster); A2930, A2938, A3365, A3371, A4411, A4413, H4170, H4481, H4615, H5280	O	O	O	O				
* *Tanacetum vulgare* L. (common tansy); H5190, H6344							R	R
* *Taraxacum erythrospermum* Besser (red-seeded dandelion); A3882	R							

* *Taraxacum officinale* F.H.Wigg. (dandelion); A3507, A3877, F7119, H6637, H6679	R	R	R	O			O	
* *Tragopogon dubius* Scop. (goat's-beard); A4043, F7433, H4480, H4501, H4729, H4893, H6362, W1519	R	O	O	O	O			
BETULACEAE								
Betula papyrifera Marshall (paper birch); A2969, A3561, A3620	*R*	*O*	*R*					*R*†
Corylus americana Walter (American hazelnut); A2959, A3011, A3280, F7437, H4622, H4758, H4910, H5843, H6093, H6677, P43918, W1503	*A*	*A*	*A*	*A*	*A*	*C*	*A*	*A*
BORAGINACEAE								
Cynoglossum boreale Fernald (northern wild comfrey); H6866							R	R†
Lithospermum canescens (Michx.) Lehm. (hoary puccoon); A2744, A2842, A3028, A3069, A3915, F7243, F7057, H4351, H4362, H4819, H4873, H5529, H6084, M6687	O	O	O	C	O	O	O	O
Lithospermum caroliniense (J.F. Gmel) MacMill (hairy puccoon); A2762, A2759, A3130, A4061, F7159, F7239, F7405, H3017, H4187, H4201, H4891, H5606, W1536	C	C	C	C	O†		R†	
BRASSICACEAE								
* *Alyssum alyssoides* (L.) L. (pale alyssum); F7443			R					
Arabidopsis lyrata (L.) O'Kane & Al-Shehbaz ssp. *lyrata* (lyrate rock-cress); A2745, F7036, F7125, H4164, H4206, H4245, H4346, H4810	C	C	C	C				
Arabis pycnocarpa M.Hopkins (hairy rock-cress); A4117, F7478	R		R					
* *Barbarea vulgaris* W.T. Aiton (yellow rocket); H5988					O			
* *Berteroa incana* (L.) DC. (hoary alyssum); A3081, A3188, A4040, H4655, H4951, H5062, H6363, W1524	R	O	O	C	O	O	R†	
Boechera grahamii (Lehm.) Windham & Al-Shehbaz (spreading-pod rock-cress); A3029, A3052, A3529, H6327, H6692, Hg275	O	O	R		R			
* *Lepidium densiflorum* Schrad. (prairie pepper-weed); A3154, A3191, A4041, H6335, H6386	R		O	R	R			
Turritis glabra L. (tower mustard); H6141, H4423, H5673, H5826, H6358, H6588			R				R	R
CAMPANULACEAE								
Campanula rotundifolia L. (bluebell); A3127, A3165, A3306, A4081, F7162, F7446, H4398, H4097, H4232, H4421, H4633, H5633, H5643, H5675, M6738, W1545	C	C	C	A	O	C	C	O
Lobelia spicata Lam. (pale-spike lobelia); A3568, A3572, H6278		O	O					
CAPRIFOLIACEAE								
Lonicera dioica L. (red honeysuckle); A3913, A4115, H4357, H7047, Koch (9482)	R	R			R		R	R
* *Lonicera morrowii* A. Gray (Morrow's honeysuckle); A3082	R							
* *Lonicera ×bella* Zabel (showy bush honeysuckle); A3896	R							
Symphoricarpos albus (L.) S.F.Blake (snowberry); A3318, A4242, H4499, H4551, H5617, H5725, H6837, H7203				R	O	R	R	R

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APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
CARYOPHYLLACEAE								
* *Cerastium fontanum* Baumg. (common mouse-ear chickweed); F7263			R					
* *Scleranthus annuus* L. (annual knawel); A4092, A4230, H5056, H5447, H6569, M6756				O	R	R	R	O
Silene antirrhina L. (sleepy catchfly); A3121, A3140, A3527, A3554, F7425, F7463, H4487, H6383	O	O	O	O				
* *Silene latifolia* Poir. (bladder campion); A3201, A3531, F7453, H4360, H4399, H6390, H6408	R	O	O	O	O	O†	O	
* *Silene vulgaris* (Moench) Garcke (bladder campion); H4396, H5061					O			
* *Stellaria graminea* L. (common stitchwort); A3910		R						
Stellaria longifolia Willd. (long-leaved stitchwort); A3911, H6688		R						
CELASTRACEAE								
Celastrus scandens L. (American bittersweet); F7250, H4370	O†		O					
CISTACEAE								
Crocanthemum bicknellii (Fernald) Janch. (Bicknell's rock-rose); A2907, A3571, A3272, F7407, F7448, F7449, H3102, H4085, H4171, H4322, H4452, H4453, H4470, H4474, H4493, H4957, H5046, H6270, M6732, M7453, W1509, W1529	C	C	C	C	C	C	C	C
Crocanthemum canadense (L.) Britton (Canada rock-rose); A2761, A3563, F7176, H4090, H4182, H4415, H5946, H4668, H6336, H6392, H6567, H6876, H6885, P43902, W1492	O	C	O	O	O	O	R	O
Hudsonia tomentosa Nutt. (beach heather); A2957, A2967, A3086, A3500, H4578, H5254, H5257, H5575		O		R				O
Lechea intermedia Britton (pinweed); A2892, A3253, A3284, A4229, F7470, F7519, H70, H4582, H5187, H5258, H5952, H4659, H4671, H6607, H6621, H6639, H7134, H7200, P43921	C	C	O	O	O	O	O	O
Lechea stricta Britton (bushy pinweed); A3598, H-70, H3109, H5066, W1510	R	O	R				R	
CONVOLVULACEAE								
Calystegia sepium (L.) R. Br. (hedge bindweed); H4447, H5751			O					
Calystegia spithamaea (L.) Pursh (low bindweed); A3133, A4080, F7164, H4359, H4376, H4420, H4963, H5607, H5632, M6751		R	O	C	C	C	O	O
* *Convolvulus arvensis* L. (field bindweed); Taylor (147)					R			
CORNACEAE								
Cornus foemina Mill. subsp. *racemosa* (Lam.) J. S. Wilson (gray dogwood); A3169, A3363, A4095, H4598, H6877	O	O	O		O			
DIERVILLACEAE								
Diervilla lonicera Mill. (bush honeysuckle); A3305, A4087, A4108, F7251, F7476, H4355, H4575, H4962, H5289, H5609, H5677, H6262, P43908	R		O	C	C	O	O	C

ERICACEAE								
Arctostaphylos uva-ursi (L.) Spreng. (bearberry); A2956, A2960, A2973, A3014, A3307, A3613, H4515, H4570, H4588, H4754, H6487, H6659, P44026	R	R	R	O	O	C	O	C
Chimaphila umbellata (L.) W.P.C. Barton (pipsissewa); H6366, H4781				R			R	
Epigaea repens L. (trailing arbutus); H4998, H5385, H5435, H6048, H6088, H6847							R	R
Gaultheria procumbens L. (wintergreen); A2968, H4756, H5261, H5384, H6367, M6679	R			R	O	O	O	C
Gaylussacia baccata (Wangenh.) K. Koch (black huckleberry); A3194, A3259, F7160, F7224		R	O					
Vaccinium angustifolium Aiton (low blueberry); A2749, A3073, F7049, H4086, H4339, H4466, H4812, H4874, H4875, H5823, H6638, M6680	C	C	C	A	C	C	C	C
EUPHORBIACEAE								
Euphorbia corollata L. (flowering spurge); A2787, A3167, H3093, W1488, W1532	O	O						
* *Euphorbia cyparissias* L. (cypress spurge); A2840, H4403, H4879, H5019, H5619		O	O	O	O			
Euphorbia geyeri Engelm. (Geyer's sand-mat); A2737, A2904, A3248, A3346, H4720, W1573	R	R						
Euphorbia glyptosperma Engelm. (rib-seed sand-mat); A3636, A4179, A4228, A4384, F7447, H4163, H6333, W1525		R	O	R	R			
Euphorbia maculata L. (spotted sand-mat); A3330, H5263, H5055, H6018, H6346, H6404, H6571, W1522, Richardson (3587)	R	R					R	R
* *Euphorbia virgata* Waldst. & Kit. (leafy spurge); A3192, H6129, H6321			R		C			
FABACEAE								
Amorpha canescens Pursh (lead plant); A2888, A4176, F7409, H4217, H4222, H4460, W1485	C	C	O					
Amphicarpaea bracteata (L.) Fernald (hog peanut); H5284			O					R†
Astragalus canadensis L. (Canada milkvetch); A3593	R							
Dalea candida Michx. ex Willd. (white prairie clover); A3228, A3569, A4259, H3097, H6279, W1501	O	O	R					
Dalea purpurea Vent. (purple prairie clover); A2880, A4256, F7428, H3095, H4457	O	O	O					
Dalea villosa (Nutt.) Spreng. (silky prairie clover); A2886, A4372, H4160, W1572	C	C						
Desmodium canadense (L.) DC. (showy tick-trefoil); A3610, H4446, H4462		R	O					
* *Kummerowia stipulacea* (Maxim.) Makino (Korean bush clover); H150, W1521		R	R					
Lathyrus venosus Willd. (veiny pea); A3164, A4053, F7161, F7244, H4235, H4528	O	O	O		R†			R
Lespedeza capitata Michx. (round headed bush-clover); A2932, A3493, F7398, H4161, M7438, W1493	C	O	O	R				
* *Lotus corniculatus* L. (bird's foot trefoil); A3124, A3578, A4056, H4436, H4559, H6570, H6894		R	R	O	O	O		O
Lupinus perennis L. (wild lupine); A2753, A3066, F7179, F7236, F7427, H4233, H4375	C	C	O					
* *Melilotus albus* Medik. (white sweet clover); A3680, F6283, H6330, H6347		O			R			R
* *Robinia pseudoacacia* L. (black locust); H4672, H5059			R		O			
* *Securigera varia* (L.) Lassen (crown vetch); A3584, A4068		O	R					

(*Continued on next page*)

APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
* *Trifolium arvense* L. (rabbit-foot clover); A3679, F7430, H6282, H6489, H6564		O	O	C	C			
* *Trifolium aureum* Pollich (yellow hop clover); F7168, H6131, H6281		R	O					
* *Trifolium pratense* L. (red clover); A3557, F7174, H4404	R	O	O†	O†	O			
* *Trifolium repens* L. (white clover); F7170, H4393		O		R†	O			
Vicia americana Willd. (American vetch); A3577, A4038	R	O						
* *Vicia cracca* L. (cow vetch); H4267, H4730		O	O					
* *Vicia villosa* Roth (hairy vetch); F7246, H4319, H4320, H5028, H5569		R	O					
FAGACEAE								
Quercus alba L. (white oak); A4116	R							
Quercus ellipsoidalis E. J. Hill (Hill's oak); A2751, A3005, A3268, A3320, A3488, A3497, F7044, F7045, F7468, H4335, H6094, H6289, H6317, W1574	A	A	A	A	A	A	A	A
Quercus macrocarpa Michx. (bur oak); A2954, A2961, A2972, A3319, F7046, F7450, H4334, H6288, H6329, W1502	A	A	A	A	C	C	C	
Quercus rubra L. (red oak); H6253, H6849							R	R
GENTIANACEAE								
Gentiana andrewsii Griseb. (bottle gentian); Hg393		R						
Gentiana puberulenta J.S.Pringle (downy gentian); Hg392		R	R†					
GERANIACEAE								
Geranium bicknellii Britton (Bicknell's geranium); H4759, H4909, H4914						R	R	R†
HYPERICACEAE								
* *Hypericum perforatum* L. (common St. John's wort); A3324, H4437, H4780, H4913, H6284, H6337					O	O	O	O
LAMIACEAE								
Agastache foeniculum (Pursh) Kuntze (fragrant giant hyssop); A3227, A4258, F7460, H4459, H4732, H5754, H5942, H6417, W1504	C	C	C	O		R		
Hedeoma hispida Pursh (rough false pennyroyal); A3122, A3525, H5576	R	R						
Monarda fistulosa L. (bergamot); A3246, F7466, H4216, H4593, H5727, H6368, H6339, H6414, W1513	C	C	C	C	C	C	O	O
Monarda punctata L. (dotted horsemint); A3237, A3616, H4234, H4185, H5951, H6381		O	O	R				
Prunella vulgaris L. (heal-all); H4441			O					
Pycnanthemum virginianum (L.) Durand & Jackson (Virginia mountain mint); A3367, Hg396		R						
Scutellaria parvula Michx. var. *leonardii* (Epling) Fernald (small skull cap); A3528, A3145, H7016	R	R						
Stachys arenicola Britton (hedge-nettle); A2326, A3218, A3573, F7462, F7516, H442, H4494, H6334, H5726, H5833, H6385	O	O	O	C	C		C	R†

MOLLUGINACEAE								
* *Mollugo verticillata* L. (carpetweed); A3314, A4348, F7417, H4241, H4719, H6324, H6342, W1520, W1575	R	O	O	O	O		O	O
MONTIACEAE								
Phemeranthus rugospermus (Holz.) Kiger (prairie fame-flower); A4049	O							
MYRICACEAE								
Comptonia peregrina (L.) J. M. Coult. (sweet-fern); A2962, A2979, A3256, A3269, F7118, F7469, H4337, H4354, H5440, H5669, H6049, M6686, M6734, P43905		O	C	A	C	O	C	C
MYRSINACEAE								
Lysimachia ciliata L. (fringed loosestrife); W1528		R						
Lysimachia quadrifolia L. (whorled loosestrife); A2483, A3184, A3559, A4244, F7458, H4391, H6879, P43900		O	O	R	O	O	R†	
Trientalis borealis Raf. (star flower); H4901, H6836							O	O
NYCTAGINACEAE								
Mirabilis albida (Walter) Heimerl (pale umbrella-wort); A2796, A3189, A3225, A3597, H6558, W1512	O	O	O		R			
Mirabilis nyctaginea (Michx.) MacMill. (wild four o'clock); H5290			R					
ONAGRACEAE								
Chamerion angustifolium (L.) Holub. (fireweed); A3215, A3678, A4241, H4461, H4464, H4521, H5650, H6258	R	R	R	O	O†	O	O	O
Oenothera biennis L. (common evening-primrose); A3244, A3277, A3628, A4416, F7410, H4100, H4204, H4533, H4579, H5943, H6264, H6559, M7443, P43899	O	O	O	C	C	C	O	O
Oenothera clelandii W.Dietr., P.H.Raven & W.L.Wagner (Cleland's evening-primrose); A3357, H6985, Hg383, M6744		R				R		
Oenothera oakesiana (A.Gray) S.Watson & Coult. (Oakes' evening-primrose); H4087, H4424, H4552, H4775, H5041, H5057, H5287, H7044, H7052, W1483		R	O	O	R	R	O	O
Oenothera perennis L. (small sundrops); A3582		R						
Oenothera villosa Thunb. (hairy evening-primrose); A3229, A3235, A3243, H-73	O		R					
OROBANCHACEAE								
Castilleja coccinea (L.) Spreng. (Indian paintbrush); A3047, H4366		O	O					
Melampyrum lineare Desr. (narrow-leaved cow-wheat); A2488, A3265, A3621, A4239, H7046, H7133, M6733			R	R		O	R	O
Pedicularis canadensis L. (wood betony); A2758, A2843, A3076, F7121, H4353, H4390, H4817, H4870, H6355, M6695	R	O	O	C	C	O	R†	O
OXALIDACEAE								
Oxalis dillenii Jacq. (southern yellow wood-sorrel); Hg384		R						

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APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
PAPAVERACEAE								
Capnoides sempervirens (L.) Borkh. (pale corydalis); H4912, H5631, H6099, Mahoney (110), Taylor (143)				R	R	R	R	
PLANTAGINACEAE								
* *Linaria vulgaris* Mill. (butter and eggs); A3236, H6597, H5829, W1576	R	R					O	O
Nuttallanthus canadensis (L.) D.A.Sutton (annual toadflax); A3087, A3196, H5580		R	R	R†				
Penstemon gracilis Nutt. (lilac penstemon); A3123, A3148, H4228, H5009, H6136	O	O	O					
Penstemon grandiflorus Nutt. (large-flowered penstemon); A3150, A4058	O		R					
* *Plantago lanceolata* L. (English plantain); H6568								R
* *Plantago major* L. (broad-leaved plantain); H6606, H7051						R	O	
* *Plantago patagonica* Jacq. (woolly plantain); A3168, A3558, F7208, H6387, H6332, H5836, H6275	O	O	O	R	O		O	
Plantago rugelii Decne. (American plantain); A3556, A3579, H4488, H6276, H4656, H5835, H6351	R	O	O	R		O	O	O
Veronicastrum virginicum (L.) Farw. (Culver's root); A3210, A3361, H4208, H4535, H4734	O	O	O					
POLEMONIACEAE								
Phlox pilosa L. (prairie phlox); A2763, F7122, F7207, F7240, H4230, H4367, H4888, H5622, H5760, W1515	C	C	C	C				
POLYGALACEAE								
Polygala paucifolia Willd. (fringed polygala); H6653							R	
Polygala polygama Walter (racemed milkwort); A2784, A3144, A3158, A4090, F7166, F7415, H4096, H4224, H4486, H4996, H5034, H5054, H5209, H5670, M6737, M7459	O	O	O	C	O	O	O	O
Polygala sanguinea L. (field milkwort); A3368, H3094, H5016		R	O					
Polygala senega L. (Seneca snakeroot); A3132, H5614				R				
POLYGONACEAE								
* *Fallopia convolvulus* (L.) Á.Löve (black bindweed); A3611, A4109, F7442, H4101, H6298, H6379, H6557, H5834, H6863, M7462, P43914	R	O	O	O	O	O	O	
Persicaria lapathifolia (L.) Delabare (curly-top knotweed); H4104, H6416, H6610						O		
* *Persicaria maculosa* Gray (spotted lady's thumb); H6578							O	
Persicaria pensylvanica (L.) M.Gómez (Pennsylvania knotweed); A4341	R							
Polygonella articulata (L.) Meisn. (coastal joint-weed); A2826, A2929, A2738, A3347, A4432, H4181, H4577, H5262, H5298, H6553, H6590, Hg339, P43887	O	O	O	C	O	O	O	O
* *Polygonum aviculare* L. (common knotweed); A3627, A4342	R		R					

* *Rumex acetosella* L. (sheep sorrel); A3297, A3512, A4050, A4093, F7173, F7233, F7456, H4433, H6850, H6851, H6895	R	O	O	R†	R	O	R	R
* *Rumex crispus* L. (curly dock); H5830								R
RANUNCULACEAE								
Anemone cylindrica A. Gray (thimbleweed); A3128, A3149, F7178, F7248, F7406, H4231, H4449, H4556, H4640, H5030, H5613, H5616, M7441, W1484	O	O	O	C	O			
Anemone patens (L.) Mill. (pasqueflower); A2829, A2835, A2980		O	R	R				
Anemone quinquefolia L. (wood anemone); A2750, A3003, H4813, H6085, H6636, H6691, H6843, M6682	R	O	O†	O	O	R	O	O
Aquilegia canadensis L. (red columbine); A3062, A3077, A3504, F7163, H5615, H5674, H6128	O	O	O	R				O
Delphinium carolinianum Walter subsp. *virescens* (Nutt.) R. E. Brooks (prairie larkspur); A3152, H3089, H4225	O	R	R					
Ranunculus rhomboideus Goldie (prairie buttercup); A2743, A2844, A2984, A3007, F7038, H4374, H5610, H6033, H6036	C	O	O	R				
Thalictrum dasycarpum Fisch. & Avé-Lall. (purple meadow-rue); A3216, A3580	R	R						
RHAMNACEAE								
Ceanothus americanus L. (New Jersey tea); A2937, A3183, A4097, A4178, A4240, F7438, H4220, H6880, H7018, H7135, W1544	O	O	O	R	R		R	
Ceanothus herbaceus Raf. (inland New Jersey tea); A2764, A3126, A3193, A4065, H3708, H4126, H4408, H4489, H4572, H4895, H4955, H5031, H5612, H6403, P43911, W1511, Spickerman (0017)	C	C	O	C	R	O	R	R
ROSACEAE								
Amelanchier interior Nielsen (inland Juneberry); A2752, A3006, A3008, A3012, F7091, H6098, H6323, H6662. H4816	O	O	O	O	O		O	O
Amelanchier spicata (Lam.) K. Koch (dwarf serviceberry); A2746, A3004, A3009, F7037, F7117, F7252, H4333, H4384, H4380, H4646, H4878, H4811, H6090, H6259, H6656, M6697	O	O	O	A	O	C	C	C
Crataegus macrosperma Ashe (big-fruit hawthorn); H5253								R
Drymocallis arguta (Pursh) Rydb. (prairie cinquefoil); A3220, A3249, A4232, H4215, H4221, H4392, M6752, P43920	O	O	O	O	O	O		
Fragaria vesca L. (woodland strawberry); F7040, H4899, H7055			R	C†			O	O
Fragaria virginiana Mill (wild strawberry); A2740, A2841, A3070, A3492, H4388, H4818, H4871, H6082, H6640, H6858, M6685	O	O	O	A	O	O	C	C
Geum fragarioides (Michx.) Smedmark (barren strawberry); H5438, H6096, H6354							O	O
Geum triflorum Pursh (prairie smoke); A4112, F7120	R	R						

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APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
* *Potentilla argentea* L. (silvery cinquefoil); A3180, A3185, A3251, H4349, H4405, H4484, H4645, H4952, H5646, H6345, H6411	O	O	O	O	O	O		O
Potentilla norvegica L. (rough cinquefoil); A3156, A3214, A3625, H4432, H5647, H6293, H6325	O	O†	O	C	O	C	O†	C
* *Potentilla recta* L. (rough-fruited cinquefoil); A3198, F7185, H4642, H6280, H6338, W1537		R	O	O	R			
Potentilla simplex Michx. (common cinquefoil); A2778, A3079, F7145, F7171, F7459, H4368, H5605	O	O	O	C				
Prunus americana Marshall (American plum); F7041, F7052			R					
Prunus pensylvanica L.f. (pin cherry); A2741, A3276, A3878, H4379, H4511, H6374, H6654	O	O	O†	C	R		O	O
Prunus pumila L. (sand cherry); A3530, A3270, F7124, H4345, H4569, H4592, H4877, H5329, H5333, H5962, H6249, H6657, H6675, M6678, M7124, W1500	C	C	C	C	O	O	C	C
Prunus serotina Ehrh. (black cherry); A3278, A3522, H4526, H4647, H4666, H6252, H6846	R			O†		O	O	O
Prunus virginiana L. (chokecherry); A2949, A3489, F7123, H4336, H4876, H5297, H6095, H6857, M6698, W1538	C	C	C	C	O	O	R	O
Rosa acicularis Lindl. (prickly rose); A3129, A3177, A4042, F7235, F7411, H4207, H4377, H4532, H5039, H5635, H6319, H6592, H6841, H7201, W1494.1	O	O	O	C	O		C	C
Rosa arkansana Porter (prairie rose); A2791, A3197, A3594, F7467, H4203, H7149, M7458	O	O	O		O			
Rosa blanda Aiton (smooth rose); A2484, A2487, F7229, H4348, H4654, H5195, H5608, H6839, W1494		O	O	C	O	O	O	O
Rosa carolina L. (Carolina rose); H4089, H4371, H4406, H4407, H4653, H4658, H5728, H6269, H6372, H6898, H7017, H7045, H7050, M6747		O	O	O	C	O	C	
Rosa woodsii Lindl. (western rose); H5032				O				
Rubus allegheniensis Porter (blackberry); A3245, H4662, H6256, H6371, H6407, H6349	O			C		O	C	O
Rubus flagellaris Willd. (common dewberry); A2765, A2781, A4046. A4194. A4245, H5637, H5671, H6127, H6676, H6694, H6842, M6767, P43903	O	O†	O	O	C	C	C	C
Rubus pensilvanicus Poir. (blackberry); A4057			R					
Rubus setosus Bigelow (bristly blackberry); A4350, A4071	O	O						
Rubus strigosus Michx. (red raspberry); A3261, A4111, H6415, H6587	O	O	O†	O†		C	C	O†
Sibbaldiopsis tridentata (Aiton) Rydb. (shrubby five-fingers); A2489, A3495, H4092, H4434, H4514, H4586, H4752, H4997, H5639, H6273, M6736				C	O	C	C	C
* *Sorbaria sorbifolia* (L.) A.Braun (false spiraea); M7463		R						
Spiraea alba Du Roi (meadowsweet); A2913, A3631, A4175, F7475, H4573, H6382	O	O	O	O	O			
RUBIACEAE								
Galium boreale L. (northern bedstraw); A3134, A3170, A4063, F7180, F7241, F7457, H4200, H4226, H4372, H4382, H5648, H6384, W1514	C	C	C	C	O	O†		

Houstonia longifolia Gaertn. (long-leaved bluets); A3085, A3157, A3211, A4067, A4079, H4199, H4237, H4249, H4364, H4397, H4643, H4896, H5036, H5628, P43915	O	O	O	C	O	O	R†	
SALICACEAE								
Populus grandidentata Michx. (big-tooth aspen); A3279, A3490, A3508, H6554		O		R	O			O
Populus tremuloides Michx. (trembling aspen); A2951, A2953, A3267, A3348, A3499, F7482, H5528, H6257, H6297, H6320	O	O	C	C	C	O	O	O
Salix discolor Muhl. (pussy willow); A2830, A2831, F7088, H4342		O	O					
Salix humilis Marshall (prairie willow); A2964, A2976, A2834, A3166, A3200, A3266, F7116, F7441, H4340, H4757, H6037, H6045, H6050, H6658, M6699	C	C	C	A	C	C	C	C
SANTALACEAE								
Comandra umbellata (L.) Nutt. (bastard toadflax); A3065, A3063, F7048, F7126, H4344, H4429, H4815, H4869, H6883	O	O	O	C	O	O†		O
SAPINDACEAE								
Acer negundo L. (box elder); A2950, F7042	R		R					
Acer rubrum L. (red maple); A2948, A4070, H5436, H6046, H6364, H6845, H6898, H6986	O	R	O†	R		O	O	R
SAXIFRAGACEAE								
Heuchera richardsonii R. Br. (prairie alum root); A3125, A3190, A3895, A4059, F7182, H4386, H4192, H4784, H5618, H6087, P43917	O	O	O	O	O	O	O	O
SCROPHULARIACEAE								
Scrophularia lanceolata Small (American figwort); A3174, F7143, H3111	R	O	O					
* *Verbascum thapsus* L. (common mullein); A3595, H29, H5042, H6300, H6331, H6359, H6369, W1499	O	O	O	O	O	O	O	O
SOLANACEAE								
Physalis heterophylla Nees. (clammy ground-cherry); A2785, A2935, H4627, F7183	O	O	R					
Physalis virginiana Mill. (lance-leaved ground-cherry); A2786, A3163, A4083, F7146, F7177, F7418, H4242, H4497, H5203, H6130, M6750, W1535	O	O	O	O	O	R		
Solanum ptychanthum Dunal (black nightshade); A4347, H4270	R		R					
VALERIANACEAE								
* *Valeriana officinalis* L. (garden valerian); H7210							R	
VERBENACEAE								
Verbena bracteata Lag. & Rodr. (creeping vervain); A3526, A3564, H6277	R		R					
Verbena hastata L. (blue vervain); A3581, A4346	R	R						
VIOLACEAE								
Viola adunca Sm. (hook-spur violet); A3027, A3494, H4814, H5444, H4587, H4785, H4872, H4900, M6681			O	A	O	C	C	C

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APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
Viola pedata L. (bird's-foot violet); A2742, A3074, F7055, F7420, H4341, H4347, H4809, H4887, H4907, H5035, H5294, M6689	C	C	C	A		R	R	
Viola pedatifida G.Don (prairie violet); A3067, A3916, F7095, H4243, H5496, H6690	O	R	O	O				
Viola sagittata Aiton (arrow-leaved violet); F7092		O						
MONOCOTS								
ALLIACEAE								
Allium stellatum Ker Gawl. (prairie onion); A2330, A2331, A2335, A2336, A4257, A4260, A4364, F7396, H3090, H4172, W1516	R	O	O					
ASPARAGACEAE								
* *Asparagus officinalis* L. (asparagus); F7230, H5288			O					
COMMELINACEAE								
Tradescantia occidentalis (Britton) Smyth (prairie spiderwort); A3160, F7212, F7432, H4219, H4229, H4718, M7440, W1540	C	O	O					
CONVALLARIACEAE								
Maianthemum canadense Desf. (Canada mayflower); A2748, A3083, A3496, F7165, H4361, H4954, H6097, H6251, H6285	R	O	O†	O	O	O	C	O
Maianthemum racemosum (L.) Link (false Solomon's seal); H4623			R					
Maianthemum stellatum (L.) Link (starry false Solomon's seal); A2757, A3058, A3071, A3136, A3503, F7483, H4373, H4898, H5006, H6886, W1577	O	O	O	C	O		O†	O†
Polygonatum biflorum (Walter) Elliott (giant Solomon's seal); A3075, A4064, F7484, H5281, H6119, W1530	O	O	O					
Uvularia sessilifolia L. (sessile bellwort); A2747, A3031, A3880, A4243, H4496, H4868, H5526, H6260, H6356	R	O	O	R	O		C	O
CYPERACEAE								
Bulbostylis capillaris (L.) C.B.Clarke (hair sedge); A2486, H6420						O		
Carex adusta Boott (brown oval sedge); H4908, H5527, H6875							R	
Carex bicknellii Britton (Bicknell's oval sedge); Hg942			R					
Carex brevior (Dewey) Mack. (fescue sedge); A3524, A4044	R							
Carex foenea Willd. (bronze-headed oval sedge); H6122			R					
Carex houghtoniana Dewey (Houghton's sedge); H6867							R	
Carex muehlenbergii Willd. (Muhlenberg's sedge); A3084, H5012, M6753	R		R			R		
Carex pellita Willd. (broad-leaved woolly sedge); A3078, F7154, H5571, H6687, Hg255	R	O						

Carex pensylvanica Lam. (common oak sedge); A3033, A3035, A3137, A3143, A3178, A4047, A4048, H6693, H4883, H4906, H5053, H6086, M6684	C	C	C	A	C	O	C	A
Carex richardsonii R.Br. (Richardson's sedge); A2647, A2977, A3010, A3013, A3026, A3914, H5434, Hg261	R	R	R	R				
Carex scoparia Willd. (broom sedge); H4485				R				
Carex siccata Dewey (dry-spiked sedge); A3080, F7152, F7231, F7414, H4338, H4365, H4894, H5047, H5644, H6100, H6696, H6860	C	C	C	O	R		R	
Carex tonsa (Fernald) E. P. Bicknell var. *tonsa* (shaved sedge); A3302, A3034, F7043, H5441, H6014, H6031, H4782, H4911, Hg516, M6683, Tans (667)	R	R	O	C		O	O	
Cyperus houghtonii Torr. (Houghton's nut sedge); A3322, A3329, F7416, H4205, H4483, H4495, H4639, H5044, H5201, H5838, H5841, H5938, H5949, H6377, H6602, M7446, P43893		O	O	C		O	O	O
Cyperus lupulinus (Spreng.) Marcks (Great Plains flat sedge); A3353, A4250, H3124, H4490, H5758, F7451, H5018, M7445, W1527	O	O	O	R				
Cyperus schweinitzii Torr. (Great Plains sand sedge); A2794, A2887, A3238, A3241, A4251, F7434, H4193, H4209, H4451, H4691, H4726, W1517, W1581	C	O	O	R				
Cyperus strigosus L. (false nut sedge); H4167		R						
Scleria triglomerata Michx. (stone-rush); A3369, A3405, H5577		R	R					
HYPOXIDACEAE								
Hypoxis hirsuta (L.) Coville (yellow-star grass); A3518, H6686		R						
IRIDACEAE								
Sisyrinchium campestre E. P. Bicknell (prairie blue-eyed grass); A3050, A3060, A3068, A3484, A3505, A3917, H6133, F7242	O	O	O					
Sisyrinchium montanum Greene (mountain blue-eyed grass); F7128, H4400, H4892, H5620, H5623, H4960		R		C	R			
JUNCACEAE								
Juncus greenei Oakes & Tuck. (Greene's rush); H3103, H4454, H4744, H4746		R	R					
Juncus tenuis Willd. (path rush); H5017, H6987, H6352, H7205, Hg296		O	O			O		O
Luzula multiflora (Ehrh.) Lej. (common woodrush); A3048		R	R					
LILIACEAE								
Lilium philadelphicum L. (wood lily); A3323, A3583, H4463, H4995, H5291, H5408, H6254, H6322, M6735		R	R	O	O	O	R	R
ORCHIDACEAE								
Liparis loeselii (L.) Rich. (Loesel's twayblade); A3356, Hg397		R						
Spiranthes cernua (L.) Rich (sphinx ladies' tresses); H4675, Hg394		R	R					
Spiranthes lacera (Raf.) Raf. (northern lady's tresses); H4093						R		R†

(*Continued on next page*)

APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
POACEAE								
* *Agrostis gigantea* Roth (red top); A4113, Hansen (2061)	R							O
Agrostis hyemalis (Walter) Britton, Sterns & Poggenb. (winter bent grass); H5840, H6852							R	
Agrostis scabra Willd. (rough bent grass); A2485, A3179, A3186, A3263, A3596, A3634, A4085, A4102, A4231, H3101, H4401, H5013, H5050, H5313, H5964, M6754	C	C	C	C	C	C	O	O
Andropogon gerardii Vitman (big blue-stem); A2901, A3291, A3708, F7397, H4555, H6294, H6365, H6274, M7447, P43888, W1506	A	A	A	A	A	A	A	A
Anthoxanthum hirtum (Schrank) Y.Schouten & Veldkamp (sweet grass); A3482, A3879, F7100	R	R						
Aristida basiramea Vasey (fork tip three-awn grass); A2943, A2944, A2945, A3321, A3696, A3707, H34, H5295, H6560, Hg382, P43890	O	O	O	O	O	O	O	
Aristida tuberculosa Nutt. (beach three-awn grass); A2927, A3345, A3358	O	R						
* *Avena sativa* L. (oats); H4584								R
Avenella flexuosa (L.) Drejer (crinkled hair grass); A3288, A3303								O
Bouteloua curtipendula (Michx.) Torr. (side-oats grama grass); A2882	O							
Bouteloua hirsuta Lag. (hairy grama); A2883	O							
* *Bromus inermis* Leyss. (smooth brome); A3116, A3172, A3286, H4363, H6856	O	O			O		R	O
Bromus kalmii A.Gray (Kalm's brome); A2490, A2931, A3223, A3257, A3292, A3317, A3738, A4110, F7464, H4525, H4553, H5945, M6739, W1487	O	O	O	C	O	O	O	O
* *Bromus tectorum* L. (cheat grass); A3519		R						
Calamovilfa longifolia (Hook.) Scribn. (prairie sand reed); A2879, A4409, H4727	R	R						
Cenchrus longispinus (Hack.) Fernald (sandbur); A2891, A3285, A3617, H5753, M7456, W1526	O	O	O	O				R
Danthonia spicata (L.) Roem. & Schult. (poverty oat grass); A3118, A3171, A3264, A3711, A4045, A4089, A4104, H4418, H4455, H4475, H4641, H5051, H6873, M6731, M6741, M6742	C	C	C	A	C	C	C	C
Dichanthelium acuminatum (Sw.) Gould & C. A. Clark var. *fasciculatum* (Sw.) Gould & C.A.Clark (hairy panic grass); A2780, A3141. A3159, A4086, A4099, F7408, F7461, H4248, H5302, H6133, H6855, H6896	C	C	C	C	C	O	O	O
Dichanthelium columbianum (Scribn.) Freckmann (puberulent panic grass); F7237, F7485			R					
Dichanthelium depauperatum (Muhl.) Gould (poverty panic grass); A2869, A3176, A4078, H4247, H4482, H5626, H5642, Hg250, M6755	C	O		O	O	O		
Dichanthelium linearifolium (Britton) Gould (linear-leaved panic grass); H5000, H5625				O				R
Dichanthelium meridionale (Ashe) Freckmann (slender panic grass); M6748						R		
Dichanthelium oligosanthes (Schult.) Gould var. *scribnerianum* (Nash) Gould (Scribner's panic grass); A3117, A3151, A4039, F7150, F7156, F7184, H4456, M7451	O	O	O					

Dichanthelium perlongum (Nash) Freckmann (long-stalked panic grass); A2868, A3147, A3521, F7234, H5065, H6134, H6833, H6882	C	O	O				O	R
Dichanthelium villosissimum (Nash) Freckmann var. *praecocius* (Hitchc. and Chase) Freckmann (prairie panic grass); Mauritz (s.n.), Westad (s.n.)			R					
Dichanthelium xanthophysum (A. Gray) Freckmann (pale panic grass); H4428, H4524, H5301, H6409, H4669					R†	R	O	O
* *Digitaria ischaemum* (Schreb.) Muhl. (smooth crab grass); H-4, H-5, H4644, H4725, H5296, H6591, H6599, H7146, P43892		O	R	O		O	O	
* *Digitaria sanguinalis* (L.) Scop. (hairy crab grass); A3354, H5831	O						R	
Echinochloa muricata (P.Beauv.) Fernald (American barnyard grass); H6419, H6594						R	R	
Elymus canadensis L. (Canada wild rye); A2912, A3619	R		R					
* *Elymus repens* (L.) Gould (quackgrass); A3142, A3173, A3565, H4240, H5001, H5755, H4637, H6295, H6872	O	O	O	C		O	C	O
Elymus trachycaulus (Link) Gould (slender wheat grass); A3295, A4343, H4502, H4513, H6271, H6413	R				R	R	R	R
Eragrostis pectinacea (Michx.) Nees (tufted love grass); A3287, A4246, A4252, F7445, H6604			R	R		C		R
Eragrostis spectabilis (Pursh) Steud. (purple love-grass); A2889, A3599, F7401, H78, M7452	O	O	O					
* *Festuca rubra* L. (red fescue); A4088, A4114, H7148, Hansen (2042)	R				O			R
Festuca saximontana Rydb. (Rocky Mountain fescue); A3501, A3520, H6370, M6692		R		O		R		
* *Festuca trachyphylla* (Hack.) Krajina (hard fescue); H6695					R			
Hesperostipa spartea (Trin.) Barkworth (porcupine grass); A3162, A4066, F7153, F7247, F7471, H6140	C	C	C					
Koeleria macrantha (Ledeb.) Schult. (June grass); A3135, A3161, A4082, F7149, F7249, H4194, H5645, H4567, H4958, H4994, H5189, H6854, P44010	C	C	C	C	C	O	O	O
Muhlenbergia glomerata (Willd.) Trin. (marsh muhly); H4195, H4554, H5200, H5252, H5950, H6268, Hg103, P43913		O		O	O	O	O	O
Oryzopsis asperifolia Michx. (rough-leaved rice grass); H6678, H4905, H6844, M6688				R	O†	O	C	R
Panicum capillare L. (witchgrass); A3240, A3615, H4197, H6378, H4638, W1505, W1578	R	R	R	O				
Panicum virgatum L. (switch grass); A2884, F7473, H4728, H5244, H7147, M7442	O	O	O		R			
* *Phleum pratense* L. (timothy); A3912		R	O†					
Piptatheropsis pungens (Spreng.) Romasch., P. M. Peterson & R. J. Soreng (mountain rice grass); A3271, A4055, A4101, H4522, H4670, H4903, H4916, H5309, H5825, H5941, H6101, H6660, M6694, Sulman (615)		R	R	R	R†	R	C	R
* *Poa compressa* L. (Canada bluegrass); A3187, A3195, A3709, A4091, F7452, H4350, H4880, H5640, H5832, H6394, H6829, H6897, Hg118		O	O	C	O	O	O	O
* *Poa pratensis* L. (Kentucky bluegrass); A3030, A3051, A3502, H6296, M6690	C	C		C		O	O†	

(*Continued on next page*)

APPENDIX 1. (*Continued*)

Taxon	S	F	C	N	D	Mt	B	Mq
Schizachne purpurascens (Torr.) Swallen (false melic-grass); A3523, F7127, H4075, H4402, H4902, H4915, H5621, H6838, H6853, H7054	R	O	O†	R	R	R	O	R
Schizachyrium scoparium (Michx.) Nash (little bluestem); A2934, A3274, A3335, A3706, F7402, H4561, H6488, H6555, H6596, M7457, P43896, W1490	A	A	A	A	A	A	C	C
* *Setaria faberi* Herrm. (giant foxtail); H6490, H6609				R		O		
* *Setaria pumila* (Poir.) Roem. & Schult. (yellow foxtail); H5282, H6418, H6608, M7455, W1543		R	O			O		
* *Setaria viridis* (L.) P.Beauv. (green bristle grass); H4244				R				
Sorghastrum nutans (L.) Nash (Indian grass); A2885, A3327, A4410, F7419, H4162, H4620, H4634, H5207, M7436, P43922, W1508, W1546	C	C	C	C		R	R	
Spartina pectinata Link (prairie cord grass); H4549			R					
Sporobolus cryptandrus (Torr.) A.Gray (sand drop-seed); A2739, A2795, A3250, A3614, A3618, A4196, W1571	O	O	O					
Vulpia octoflora (Walter) Rydb. (six-weeks fescue); A2779, A3049, A4103		R	R	R				
SMILACACEAE								
Smilax hispida Raf. (bristly green brier); H5808			R					
Smilax lasioneura Hook. (common carrion flower); H5020			R					

BOTANICAL ASSESSMENT OF REMNANT FLOODPLAIN HABITATS ALONG PLASTER CREEK, KENT COUNTY, MICHIGAN: ASSESSING CHANGES SINCE THE 1890S

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ABSTRACT

Plaster Creek, a tributary of the Grand River, drains a 58-square mile watershed in Kent County, Michigan. Its headwaters originate in the agriculturally dominated southwestern portion of the county, and then it meanders through residential, commercial, and urban areas of Kentwood and Grand Rapids before it empties into the Grand River about one mile south of downtown Grand Rapids. Much of Plaster Creek's original floodplain, like the rest of its watershed, has been drastically altered and degraded over time due to the development of residential neighborhoods, commercial properties, agriculture, and industrial zones. Floodplains house unique assemblages of Michigan's native biodiversity and sustain stream and watershed health, warranting their preservation and restoration. Over several seasons, Calvin University Herbarium's Emma Cole Grand Rapids Flora Project inventoried seven remnant floodplain sites along Plaster Creek from near its source in Gaines Township to downstream areas within the City of Grand Rapids. A total of 438 species of vascular plants were documented for the combined seven floodplains, of which 341 (77.9%) are native. Floristic Quality Assessments were calculated for each of the sites with values ranging from a Total Floristic Quality Index (FQI) of 30.4 (Total Mean $C = 2.8$) at the smallest site with only 93 native species (78.7%), to a Total FQI of 52.7 (Total Mean $C = 3.6$) at the Ken-O-Sha Park floodplain, with 176 (82.2%) native species. The Stanaback Park floodplain had a similar number of native species, 174 (80.9%), and a Total FQI of 48.4 (Total Mean $C = 3.3$). In order to make comparisons with floristic information compiled by Emma Cole in the 1890s, a Floristic Quality Assessment was calculated based on 65 species (98.5% native) collected and reported by Cole (1901) as occurring along Plaster Creek. The Total FQI of Cole's list was 48.4 (Total Mean $C = 6.0$), and 27 of her species have a high level of fidelity to a narrow range of ecological conditions, five of which today hold Special Concern, Threatened, or Endangered status in Michigan. By comparing our inventory findings with the floristic information gathered by Cole, this study highlights changes that have taken place in the Plaster Creek floodplain over the past 120+ years, describes the present-day condition of Plaster Creek's floodplains, and can be used to inform future ecological restoration efforts along this and other local creeks.

KEYWORDS: Michigan flora, floodplain habitat, riparian, bottomland swamp, Floristic Quality Assessment, floristic inventory.

INTRODUCTION

Plaster Creek in Kent County, Michigan, with its remnant floodplain habitats presents a unique case-study for how drastically urban, suburban, and agricul-

tural development have altered the native biodiversity and ecological integrity of the stream and its watershed over time. Plaster Creek, whose headwaters are located southeast of Grand Rapids in the agricultural areas of Dutton and Caledonia (FTC&H 2008), drains a watershed of approximately 58 square miles. From these headwaters the creek meanders through the present-day City of Kentwood and into the southern portion of the City of Grand Rapids, flowing through residential, commercial, and industrial areas, before joining the Grand River about one mile south of the city center.

Plaster Creek's watershed has undergone extensive changes since the field work of Emma Cole in the 1890s. Cole, a local botanist and science educator, visited a variety of locations along Plaster Creek, which she highlighted in her *Grand Rapids Flora* (Cole 1901). Although larger expanses of natural habitat existed along Plaster Creek at the time of Cole's botanical work in the 1890s compared to today, the creek and its corridor had already been subjected to significant disturbances in her day. In 1837 Douglass Houghton (1839), while conducting the first geological survey of Michigan, visited West Michigan to investigate salt springs for possible mining. Although his search for salt was only somewhat productive, he was especially impressed by high quality gypsum outcrops (Houghton 1838) along the Ken-O-Sha (Kee-No-Shay), the original Ottawa name for Plaster Creek, which means "Water of the Walleye" (Belknap 1922, 1926).

Only three years later, in 1841, the first gypsum mine in Grand Rapids was established by Warren Granger and Daniel Ball at the site where Plaster Creek formed a waterfall that flowed over a gypsum ledge into the Grand River floodplain (Grimsley 1904). This location was known to be a sacred site for the Ottawa people, but in a few short years it was obliterated by the mining operation. Once mined, the high-quality ground gypsum provided two marketable products: an agricultural fertilizer in powdered form, and a building material when mixed with water. By 1850, this mine was yielding 60 tons of gypsum daily, and the jobs and wealth it generated earned the area the title "Happy Valley." However, the ecological fallout of this operation included clearing a large forested area, draining a wetland, and completely re-routing and channelizing the stream. In addition, the availability of local gypsum, also referred to as "land plaster," advanced farming activity in the Grand Rapids area, which prompted additional forest loss. Tailings from the mining operation so polluted the stream that walleye stopped swimming up the creek to spawn, and sadly but fittingly the original name for the waterway, "Ken-O-Sha," was replaced by "Plaster Creek" (Belknap 1922).

Forest clearing began in West Michigan in the late 1700s and had profound impacts on Plaster Creek. Trees were first logged for homesteading and for agriculture and later for income generation. As forest cover declined along the upper reaches of Plaster Creek, the creek's flow cycles intensified. In 1910, Charles Garfield, who grew up in the Plaster Creek Watershed and became the first president of Michigan's Forestry Commission, wrote about the impacts of deforestation on the creek (Garfield 1910):

> [Plaster Creek] has almost nothing now in the way of tree growth from its source to its confluence with the Grand River, and instead of being the beautiful even-flowing stream throughout the year, as in my childhood, it is now a most fitful affair, full to the brim and running over at times, yet most of the year it is only a trickling rill . . ..

The extreme flow cycles that Garfield (1910) lamented have further intensified today, now exacerbated by the replacement of native vegetation with expansive impermeable surfaces (roads, parking lots, rooftops, etc.) throughout Plaster Creek's watershed. These changes to the landscape feed excessive amounts of stormwater runoff directly into the creek during rain events. The erosive forces caused by extreme runoff volumes result in high sediment loads, toxic levels of *E. coli*, and countless other harmful substances, such as road salts, pesticides, fertilizers, and hydrocarbons collecting in the creek, all of which have been documented by Calvin University researchers. By the early 2000s, as these pollutants proliferated in the creek, the Michigan Department of Environmental Quality labeled Plaster Creek as the most contaminated waterway in West Michigan, due in large part to the ecologically uninformed ways that development occurred in the watershed over time (Lee and Warners 2014; DeJong 2017).

One of the ways that uninformed development ecologically damaged Plaster Creek is by destroying much of its floodplain. Although a handful of intact, functional floodplain remnants do still exist along Plaster Creek (such as the parcels we inventoried for this project), most of the creek's original floodplain has been lost to residential neighborhoods, commercial properties, and industrial zones. The importance of the remaining healthy, intact floodplain habitat within the Plaster Creek watershed cannot be overstated. Into these floodplain zones the creek overflows during periods of high volume, and floodplain vegetation slows the water, allowing water-borne sediment to fall out of stream flow. In addition, water percolates into the floodplain soils, where plants transpire large volumes of it into the air (Hopkins 1999). These features of healthy floodplains mean that they not only reduce flooding frequency and intensity but also cause cleaner water to be transported downstream to lower reaches of Plaster Creek, the Grand River, and eventually, Lake Michigan. Furthermore, floodplains support a rich assemblage of native Michigan plants that in turn support a broad array of insects, birds, and mammals. In these ways, healthy floodplain ecosystems support healthy ecological and human communities in the Plaster Creek watershed.

OVERVIEW OF FLORISTIC QUALITY ASSESSMENTS

History and Development

Floristic Quality Assessments provide useful metric-based measures to evaluate habitat conservation value and have become increasingly influential in North America over the past 20 years (Spyreas 2019). Conservation practitioners and land managers often have a fundamental need to be able to rapidly assess the value of various land parcels with respect to natural quality and ecological integrity and thus conservation value. Well-seasoned field biologists can often make an initial professional assessment to suggest which lands may be of higher

priority for preservation or restoration, but this type of evaluation involves subjective judgments. Methods that yield objective and quantitative ecological indicators are preferable to standardize and guide such assessments. However, care must be taken when using simple assessments, which may provide little information about complex vegetation properties, such as ecological uniqueness, floristic composition, influence of non-native species, and regional distinctiveness (Spyreas 2019).

It was with these considerations in mind that the authors of *Plants of the Chicago Region* developed their objective metrics for rating the natural quality of plant communities (Swink and Wilhelm 1979). Originally referred to as the "Natural Areas Rating Index" Swink and Wilhelm (1994) later modified and refined their rating system, renaming the overall methodology Floristic Quality Assessment (FQA). The FQA system of Swink and Wilhelm (1994) is available for numerous states across the country. The Michigan FQA system was formulated in 2001 (Herman et al. 2001), and it includes detailed practical information on its application to Michigan natural areas.

Swink and Wilhelm (1994) recognized that certain species had a very high affinity for, or fidelity to, rather specific habitat conditions, whereas other plants could be found growing in a wide range of habitats. This led them to assign what they called a Coefficient of Conservatism value (*C*-value) to each native species, a value that was intended to reflect the level of fidelity each species had to its particular habitat. To illustrate this idea, one almost always encounters white fringed orchid (*Platanthera blephariglottis*) in pristine sphagnum bogs, and it is assigned a *C*-value of 10. In contrast, red maple (*Acer rubrum*) has a *C*-value of 1, since it may grow in a bog but can also be found in many wetland woods and can even be a major component of upland forests, particularly in northern areas.

Significance and Application

As a consequence of agricultural and urban development, logging, and hydrological alterations, many of the principal floristic elements of our presettlement ecosystems are poorly represented in Michigan's present landscape (Herman et al. 2001). Much of Michigan's remaining native biota has become severely restricted to small, isolated tracts of natural landscapes, which have themselves been impacted by surrounding growth and development (Zipperer 1993; Hartley and Hunter 1998; Warners et al. 2021; Crow et al. 2022). As a result, even small sites that house remnants of Michigan's native biodiversity hold much significance, and objective quantitative tools such as FQA can be used to evaluate their conservation value.

Herman et al. (2001) have set FQA thresholds (Table 1), suggesting that sites with FQI scores of 35 or higher have floristically important statewide value. FQI scores greater than 50 suggest exceptional sites that exhibit extremely high conservation value and represent a significant component of Michigan's native biodiversity and natural landscapes. Some feel that although a site's FQI values are useful, a site's mean *C*-value represents a less biased indicator of its relative conservation value, especially when comparing similar natural communities such as river floodplains (Matthews et al. 2005; Slaughter et al. 2015). However,

TABLE 1. Significance of different ranges of Native FQI as calculated under the Michigan Floristic Quality Assessment System for evaluating individual natural habitats as reflecting Michigan's native biodiversity and natural landscapes, based on Herman et al. (2001).

Native FQI	Significance of habitat quality to Michigan	Value of site to Michigan
< 20	Minimal indication of natural quality; reflects much human disturbance.	Low value.
21–34	Average quality.	Moderate value.
35–50	Sufficient conservatism and richness in native flora; high quality.	Floristically important statewide.
> 50	Rare, highly specialized or extraordinarily high quality; significant component of Michigan's remaining native biodiversity.	Extremely high value; worthy of protection and conservation.

Matthews et al. (2015) found that species co-occurred with others of similar *C*-value far more than expected by chance, thus affirming the reliability of FQAs. Slaughter et al. (2015) regard differences of mean *C*-values to be modest when calculated *within* a particular habitat type but to have significant differences if applied to sites that encompass a variety of habitat types. We consider both FQI and mean *C*-values to be helpful for practitioners involved in ecological integrity assessments, so we provide both in this paper.

MATERIALS AND METHODS

Descriptions of the Seven Remnant Floodplain Sites

Over the past decade, the Emma Cole Grand Rapids Flora Project inventoried seven remnant floodplain sites along Plaster Creek from near its source in rural Gaines Township to the crossing of Plaster Creek at Madison Avenue within the urban core of Grand Rapids (Figure 1). Much has changed since Cole's day, as we have documented with the help of Cole's (1901) detailed accounts and herbarium specimens. This paper reports the most thorough inventory of the remnant natural floodplain areas in the Plaster Creek corridor to date, providing valuable baseline reference data for the ambitious watershed restoration work that is being undertaken by Calvin University's Plaster Creek Stewards (Calvin University 2023).The sites are listed in order from farthest upstream in Gaines Township to farthest downstream in the City of Grand Rapids.

Crystal Springs (42° 50.758′N, 85° 35.602′W)

The Crystal Springs site of 2.1 ha is located in Gaines Township about one mile west of the center of the village of Dutton on the property of the Leisure Creek Condominium Association (Figure 2). Plaster Creek enters the parcel after crossing under 68th Street and flows northward through the condominium property in the northeastern portion of an area historically known as Crystal Springs. We know that Cole visited Plaster Creek at this location in the 1890s, even though she did not specifically mention Crystal Springs in her *Flora of Grand Rapids* (Cole 1901). Evidence that Cole collected here is confirmed by seven extant herbarium specimens she labeled as "Plaster Creek, Crystal Springs"—*Carex emoryi*, *C. prairea*, *C. sterilis*, *C. tetanica*, *Euphorbia commutata*, *Hierchloe odorata*, and *Dichanthelium clandestinum*—with field visits occurring May 19, 1894; May 10, 1896; May 19, 1897; and July 14, 1897 (MICHIGAN FLORA ONLINE 2011). Our inventory, conducted in 2018 at the invitation of the Leisure Creek Condominium Association and augmented in 2022, is documented by 73 voucher specimens.

Paris Park (42° 51.348′N, 85° 35.075′W)

Paris Park is an 18-ha site of undeveloped woodland along Plaster Creek that is owned by Kent County Parks (Figure 3A). There are several trails that are maintained by the City of Kentwood Parks and Recreation Department. Plaster Creek flows into the park under 60th Street SE from Gaines Township to the southwest, is joined by an unnamed tributary from the southeast, and then meanders northward towards 52nd Street SE. The park can be accessed from 60th Street SE just east of the intersection with Hanna Lake Avenue SE. Paris Park was inventoried in 2015 and 2016 by the Emma Cole Grand Rapids Flora Project and is documented by 143 voucher specimens.

Wernlund Family Property (42°51.784′N, 85° 35.049′W)

The Wernlund property floodplain is a small site of 2.3 ha on private land between East Paris Avenue and Wing Avenue in the City of Kentwood in a neighborhood accessed from the south side of 52nd Street (Figure 3B). Plaster Creek meanders through the property, entering from the south and meandering out to the north. The site is located immediately across the creek from Paris Park on the north side of Plaster Creek. The flora of the Wernlund site was inventoried in 2021 at the invitation of the property owners and is documented by 82 voucher specimens.

Covenant Park (42° 53.520′N, 85° 34.980′W)

Covenant Park occupies a large parcel of land (11.9 ha) at the southeast corner of the intersection of Shaffer Avenue and 36th Street within the City of Kentwood (Figure 4). Previously known as The Christian Reformed Recreation Center, which included Fellowship Greens Golf Course, the site is now under the ownership of the City of Kentwood and is maintained by their Parks and Recreation Department. The Plaster Creek corridor, along with its remnant forested floodplain sections, enters Covenant Park from the south, meanders through the property, and exits toward the northwest corner of the park under a bridge on Shaffer Avenue. After leaving Covenant Park, Plaster Creek eventually flows into the Stanaback Park floodplain area. While much of the creek's natural floodplain in Covenant Park had been converted to fairways, some small floodplain forest remnants remain. These forested areas were the focus of our 2021 botanical inventory work, with 114 voucher specimens documenting its flora.

Stanaback Park Area (42° 53.800′N, 85° 35.945′W)

The Stanaback Park floodplain is 21.8 ha in size and represents the single largest remnant floodplain inventoried by this project. It is located between Shaffer Avenue and Breton Road and bordered on the north by 32nd Street and by Pfeiffer Woods Drive on the south (Figure 5). The majority of this property is owned by the City of Kentwood, but some smaller privately owned parcels are included in the floodplain as well. The park features a large undeveloped wooded area adjacent to a small playground. The wooded area is comprised of a ravine system and the Plaster Creek floodplain. Plaster Creek enters the floodplain from Shaffer Avenue on the east and meanders through the site, exiting on the west under Breton Road. The floodplain has been protected by the ravine system that borders its southern edge and by the lack of recreational trails through the adjacent woods, which has minimized recent disturbance. Thus, this site represents a uniquely large intact remnant of Michigan's native floodplain biodiversity in the mostly urbanized Plaster Creek watershed. The flora was inventoried in 2021 and is documented by 285 voucher specimens.

Ken-O-Sha Park (42° 54.397′N, 85° 38.165′W)

The Ken-O-Sha Park floodplain, at 9.5 ha, occurs within the City of Grand Rapids, straddling both sides of Plaster Creek's main channel for nearly one mile just south of 28th Street (Figure 6). The park can be accessed on Ken-O-Sha Drive west of Kalamazoo Avenue. Plant collections contributing to the inventory of this site were made in 2012, 2015, and 2022 for the Emma Cole Grand Rapids Flora Project, and its flora is documented by 224 voucher specimens. This rich floodplain site is of particular interest to our project because Emma Cole (1901) references several plant species in her *Grand Rapid Flora* as occurring "near the Paris Town Hall," a historic building that still stands on Kalamazoo Avenue adjacent to Plaster Creek and the entrance to Ken-O-Sha Park.

Plaster Creek Trail at Madison Avenue Crossing (42° 54.995′N, 85° 39.215′W)

The Plaster Creek Trail floodplain is a 5 ha site located within the City of Grand Rapids and can be accessed at the bridge on Madison Avenue near the intersection of Ken-O-Sha Drive (Figure 7). Plaster Creek Trail winds along the Plaster Creek channel here through a remnant of the creek's

floodplain. Four small, somewhat disconnected, parcels of floodplain vegetation are present along the north and south sides of the creek. Plaster Creek enters this site from the south at 28th Street (ca. 0.5 mi from the Ken-O-Sha Park site) between Eastern Avenue and Madison Avenue and then flows northwest under Madison Avenue from the west of the study site. The floodplain at this site bears significant evidence of disturbance, yet some large trees and other elements of natural floodplain diversity remain, especially on the less-accessible portion on the north side of the creek. We inventoried this site in 2021, and 122 voucher specimens document the floodplain flora. This floodplain is of particular interest to our project because Emma Cole documented several plant species at Madison Avenue along Plaster Creek, as noted in her *Grand Rapids Flora* (Cole 1901) and documented by Cole's specimens on deposit at the University of Michigan Herbarium (MICHIGAN FLORA ONLINE 2011).

Botanical Inventory

During the growing seasons of 2012, 2015, 2016, 2018, 2021, and 2022, botanical inventories were conducted to assess sites along Plaster Creek, especially focusing on remnant floodplains. Sampling protocol for all sites was a meander-search throughout, conducted multiple times over the course of the growing seasons. All species encountered in the field were documented by voucher herbarium specimens or recorded as sight records. Identifications and nomenclature follow that of MICHIGAN FLORA ONLINE (2011), as this source includes both seed plants and pteridophytes and is periodically updated with taxonomic and nomenclatural changes. A total of 1,043 herbarium voucher specimens documenting the inventories are deposited in the Calvin University Herbarium (CALVIN); duplicates, where available, are deposited in the herbaria of Michigan State University (MSC) and/or University of Michigan (MICH).

In order to make comparisons between our inventories and the 1890s flora of Plaster Creek, Emma Cole's (1901) *Grand Rapids Flora* was examined for species noted as occurring at "Plaster Creek." Additionally, the MICHIGAN FLORA ONLINE (2011) database was also searched for specimens collected by Cole for which "Plaster Creek" appears on the label that might not have been so noted in her *Flora*. This yielded a list of 65 species that are likely to have occurred in the floodplain or in seepage areas at the base of steep ravines leading into the floodplain.

Floristic Quality Assessments

Floristic Quality Assessments (FQA) were conducted for each Plaster Creek floodplain site following the methodology described by Freyman et al. (2015) and Reznicek et al. (2014) and calculated using the online Universal FQA Calculator (https://universalfqa.org; Freyman et al. 2015). The FQA tool assigns each native Michigan plant species a Coefficient of Conservatism value (C-value) ranging from 0 to 10 (Reznicek et al. 2014). The C-value reflects a given species' fidelity to certain ecological conditions. For individual sites a Mean C value ($\bar{C}$) was generated ($\bar{C} = \frac{\Sigma C}{n}$). Using the Mean C-value ($\bar{C}$), which is the average of the Coefficient of Conservatism values of species in that site, a Floristic Quality Index (FQI) for the entire site is calculated as follows:

$$\text{FQI} = \bar{C} \times \sqrt{n}$$

where n is the number of species at the site. The Universal FQA Calculator generates a Native FQI and a Total FQI, the former based only on the native species present at the locality inventoried (as described above) and the latter on both native and non-native species (all non-native species have a C-value of 0).

RESULTS AND DISCUSSION

This study provided a unique opportunity to examine and compare several distinct remnant floodplain sites along what was historically a single, nearly contiguous habitat meandering for roughly 26 miles through the Plaster Creek wa-

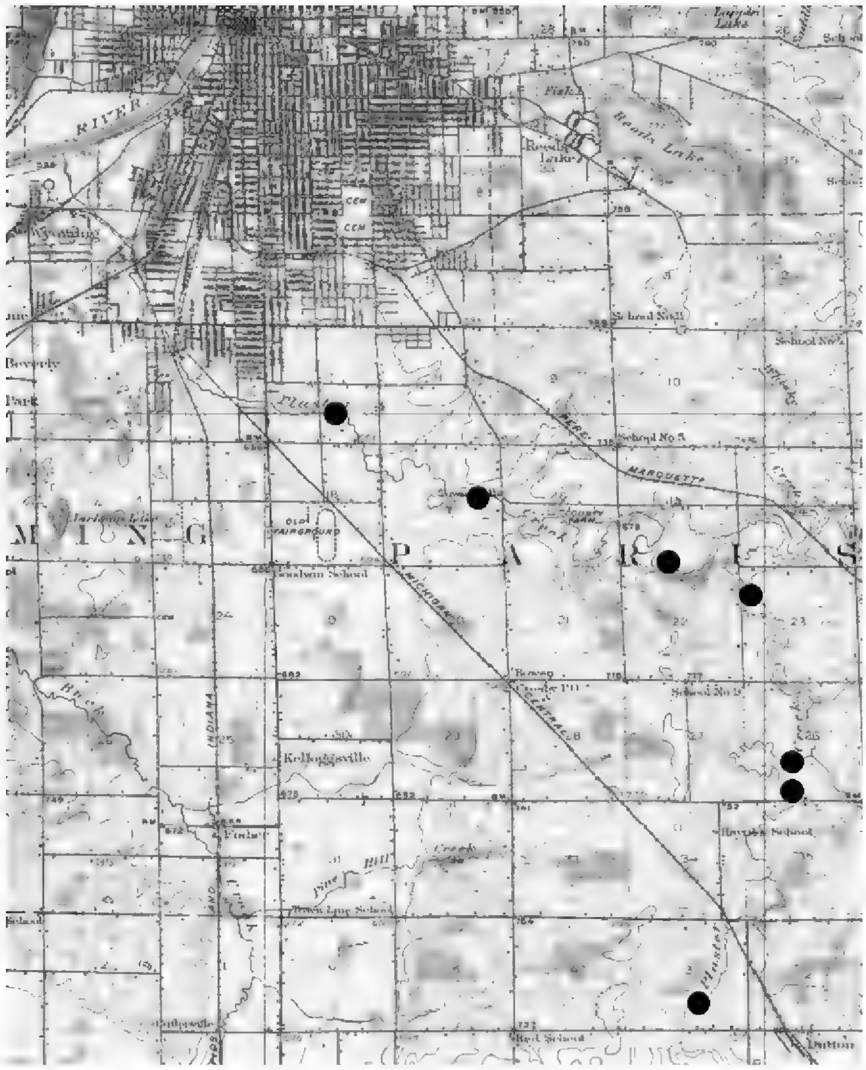

FIGURE 1. Plaster Creek study sites: south to northwest (progressively downstream): Crystal Springs, Gaines Twp.; Paris Park, Kentwood; Wernlund Property, Kentwood; Covenant Park, Kentwood; Stanaback Park area, Kentwood; Ken-O-Sha Park, Grand Rapids; Madison Avenue Crossing, Grand Rapids. 1914 Topographic Map, Grand Rapids Quadrangle, Michigan Geologic Survey/USGS.

tershed. A total of 438 species of vascular plants, native and non-native, were recorded from seven floodplain habitats along Plaster Creek as it traverses from its headwaters in Gaines Township to the City of Grand Rapids where it eventually joins the Grand River. Individual sites ranged from having a flora of 115 species (26.7% of the total combined Plaster Creek flora) to 215 species (40.1% of the combined flora) (Tables 2 and 3).

Individual Site Assessments

Among the seven floodplains inventoried in 2012–2022 (Figure 1), the Total FQI values ranged from a low of 30.4 (Total Mean C = 2.8) at the Wernlund Property to a high of 52.7 (Total Mean C = 3.6) at the Ken-O-Sha Park floodplain. The FQA metrics for each of these seven sites are given in Table 2, and Table 3 lists all species recorded (collectively) by individual site. Table 4 lists all species reported by Cole from the 1890s, as well as those from our study, that have a C-value of 8–10 (indicating a present-day high level of fidelity to a narrow range of ecological conditions); the state listing status is also indicated.

TABLE 2. Floristic Quality Assessment metrics for each Plaster Creek site, arranged in order from upstream to downstream. Estimates of area were obtained by using the Google Earth area calculator (DraftLogic 2022).

Site	Area (ha)	Total FQI	Native FQI	Total Mean *C*	Total Species	Native Species	Non-Native Species
Crystal Springs	2.14	31.1	33.5	2.9	115	97 (84.3%)	18 (15.7%)
Paris Park	17.9	47.4	50.0	3.7	164	149 (90.9%)	15 (9.1%)
Wernlund Property	2.28	30.4	34.7	2.8	118	93 (78.8%)	25 (21.2%)
Covenant Park	11.9	37.9	43.0	2.9	171	128 (74.9%)	43 (25.1%)
Stanaback Park area	21.8	48.4	52.8	3.3	215	174 (80.9%)	41 (19.1%)
Ken-O-Sha Park	(9.5)	52.7	58.4	3.6	214	176 (82.2%)	38 (17.8%)
Madison Ave. Crossing	4.91	34.6	42	2.8	153	110 (71.9%)	43 (28.1%)

Crystal Springs (42° 50.850′N, 85°35.497′W)

A total of 115 species, of which 84.3% are native, were recorded at Crystal Springs (Figure 2). The Floristic Quality Assessment (Table 2) showed a Total FQI of 31.1 and a Native FQI of 33.5. Thus, this community ranks as average quality with respect to floristic value to the state (Table 1). The Total Mean *C* was 2.9. Only three species have high-fidelity *C*-values, all *C*-8: false rue anemone (*Enemion biternatum*), swamp white oak (*Quercus bicolor*), and wahoo (*Euonymus atropurpureus*). Overall, this site was the most degraded and had the lowest species richness of our seven sites.

Paris Park (42° 51.348′N, 85° 35.075′W)

A total of 164 species, of which 90.9% are native, were recorded at Paris Park (Figure 3). The Floristic Quality Assessment (Table 2) showed a Total FQI of 47.4 and a Native FQI of 50.0. These FQI values are notably high, only exceeded in this study by those for the Ken-O-Sha Park and Stanaback Park floodplains. The Total Mean *C*, 3.7, for this site was the highest value of all seven sites in-

FIGURE 2. Plaster Creek floodplain at Crystal Springs, Gaines Twp. (Leisure Creek Condos Natural Area). Image source: Google Earth, Spot Image, 2018.

FIGURE 3. A. Plaster Creek floodplain at Paris Park. B. Plaster Creek floodplain at Wernlund property. Kentwood. Image source: Google Earth, March 18, 2021.

ventoried. Six species have high-fidelity *C*-values of 8–10: green dragon (*Arisaema dracontium*), *C*-8; three sedges (*Carex amphibola*, *C*-8; *C. laxiculmis*, *C*-8; *C. laxiflora*, *C*-8); false rue anemone (*Enemion biternatum*), *C*-8; and swamp white oak (*Quercus bicolor*), *C*-8. The site is worthy of ongoing protection and conservation according to state-wide metrics for floristic quality (Table 1; Herman et al. 2001).

The floodplain forest along Plaster Creek in Paris Park is dominated by sugar maple (*Acer saccharum*), silver maple (*Acer saccharinum*), red maple (*Acer rubrum*), boxelder (*Acer negundo*), and white ash (*Fraxinus americana*); other tree species include black cherry (*Prunus serotina*), cottonwood (*Populus deltoides*), American elm (*Ulmus americana*), sycamore (*Platanus occidentalis*), and willows (*Salix* spp.). Poison-ivy (*Toxicodendron radicans*) abounds in the floodplain. A plethora of spring wildflowers is present, including common white trillium (*Trillium grandiflorum*), southern blue flag (*Iris virginica*), bloodroot (*Sanguinaria canadensis*), Canada anemone (*Anemone canadensis*), spring cress (*Cardamine bulbosa*), spring beauty (*Claytonia virginica*), yellow avens (*Geum aleppicum*), white avens (*G. canadense*), spring avens (*G. vernum*), may-apple (*Podophyllum peltatum*), swamp buttercup (*Ranunculus abortivus*), and rue-anemone (*Thalictrum thalictroides*). Green dragon (*Arisaema dracontium*) and Jack-in-the-pulpit (*A. triphyllum*) are also remarkably frequent.

Wernlund Family Property (43.862°N, 85.585°W)

A total of 118 species, of which 78.8% are native, were recorded at this small privately owned parcel along Plaster Creek (Figure 3). The Floristic Quality Assessment (Table 2) showed a Total FQI of 30.4 and a Native FQI of 34.7; the Total Mean *C* was 2.8, equaling that of the Madison Avenue site as the lowest in

our study. Four species have a *C*-value of 8–10: green dragon (*Arisaema draconium*), *C*-8; sedge (*Carex tuckermanii*), *C*-8; swamp white oak (*Quercus bicolor*), *C*-8; and bladdernut (*Staphylea trifoliata*), *C*-9 (Table 3).

Although non-native herbaceous species (21.2%) are widespread throughout this floodplain, this property boasts a diverse and mature canopy of native tree species. We noted that 16 of the 19 tree species are native, including sycamore (*Platanus occidentalis*), swamp white oak (*Quercus bicolor*), bur oak (*Q. macrocarpa*), black maple (*Acer nigrum*), black walnut (*Juglans nigra*), and hornbeam (*Carpinus caroliniana*). The small floodplain forest also supports five maple species: sugar maple (*Acer* saccharum), silver maple (*A. saccharinum*), red maple (*A. rubrum*), box elder (*A. negundo*), and the aforementioned black maple (*Acer nigrum*). Other native trees on the property include red ash (*Fraxinus pennsylvanica*), wild black cherry (*Prunus serotina*), chinquapin oak (*Quercus muehlenbergii*), basswood (*Tilia americana*), American elm (*Ulmus americana*), and shagbark hickory (*Carya ovata*).

Despite the floodplain forest understory bearing evidence of disturbance by several non-native species, many attractive native shrubs, wildflowers, and sedges persist in the floodplain. Notable native shrubs include bladdernut (*Staphylea trifolia*), buttonbush (*Cephalanthus occidentalis*), shrubby St. John's-wort (*Hypericum prolificum*), spicebush (*Lindera benzoin*), and two species of native currants (*Ribes americanum* and *R. cynosbati*). The invasive and aggressive shrubs autumn olive (*Elaeagnus umbellata*) and multiflora rose (*Rosa multiflora*) are abundant as well.

Covenant Park (42° 53.520′N, 85° 34.980′W)

A total of 171 species, of which 74.9% are native, were recorded at this site along Plaster Creek, which had been a golf course until 2019 (Figure 4). The Floristic Quality Assessment (Table 2) showed a Total FQI of 37.9 and a Native FQI of 43.0. Eight species present at the site have a *C*-value of 8–10: green dragon (*Arisaema dracontium*), *C*-8; pawpaw (*Asimina triloba*), *C*-9; James' sedge (*Carex jamesii*), *C*-8; hairy-fruited sedge (*Carex trichocarpa*), *C*-8; flowering dogwood (*Cornus florida*), *C*-8; false rue anemone (*Enemion biternatum*), *C*-8; swamp white oak (*Quercus bicolor*), *C*-8; and black snakeroot (*Sanicula canadensis*), *C*-8.

Of the 30 tree species documented, 25 are native. These include silver maple (*Acer saccharinum*), hackberry (*Celtis occidentalis*), three species of young ash trees (*Fraxinus nigra, F. americana,* and *F. pennsylvanica*), black walnut (*Juglans nigra*), black willow (*Salix nigra*), cottonwood (*Populus deltoides*), sycamore (*Platanus occidentalis*), swamp white oak (*Quercus bicolor*), and American elm (*Ulmus americana*). Pawpaw (*Asimina triloba*), shellbark hickory (*Carya laciniosa*), and bur oak (*Quercus macrocarpa*) are also well represented.

Covenant Park supports a diversity of high-quality native wildflowers, including an impressive display of Michigan's spring flora. Among these are Canada anemone (*Anemone canadensis*), cut-leaved toothwort (*Cardamine concatenata*), spring beauty (*Claytonia virginica*), false rue-anemone (*Enemion biternatum*), both yellow trout lily (*Erythronium americanum*) and white trout

TABLE 3. List of species recorded in this study. The presence of a species at a given site is indicated by an X. The right-hand column gives the number of sites from which each species was recorded. State-listed rare species are indicated in boldface. The status of each listed species is indicated as follows: E = Endangered, T = Threatened, SC = Special Concern; locality withheld for E and T species.

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Acer negundo L.	box-elder	0	X	X	X	X	X	X	X	7
Acer nigrum F. Michx.	black maple	4	X		X		X	X	X	5
Acer platanoides L.	Norway maple	0							X	1
Acer rubrum L.	red maple	1	X		X	X		X	X	5
Acer saccharinum L.	silver maple	2	X	X	X	X	X	X	X	7
Acer saccharum Marshall	sugar maple	5	X	X	X	X	X	X	X	7
Achillea millefolium L.	yarrow	1			X					1
Actaea pachypoda Elliott	doll's eyes, white baneberry	5						X		1
Adiantum pedatum L.	maidenhair fern	6				X				1
Ageratina altissima (L.) R. M. King & H. Rob.	white snakeroot	4					X	X	X	3
Agrimonia gryposepala Wallr.	tall agrimony	2		X	X	X	X	X		5
Agrimonia parviflora Aiton	swamp agrimony	4					X			1
Agrimonia pubescens Wallr.	soft agrimony	5				X				3
Agrostis stolonifera L.	creeping bent	0	X				X	X		3
Ailanthus altissima (Mill.) Swingle	tree of heaven	0							X	1
Ajuga reptans L.	carpet bugle	0				X				1
Alisma triviale Pursh	northern water-plantain	1		X		X	X			3
Alliaria petiolata (M. Bieb.) Cavara & Grande	garlic mustard	0	X	X	X	X	X	X	X	7

Allium canadense L.	wild garlic	4	X	X	X	X	X	X	X	7
Allium tricoccum Aiton	wild leek	5						X	X	2
Allium vineale L.	field garlic	0		X	X	X	X			4
Amphicarpaea bracteata (L.) Fernald	hog-peanut	5		X	X		X		X	4
Anemone canadensis L.	Canada anemone	4		X	X	X	X			4
Anemone quinquefolia L.	wood anemone	5						X		1
Anemone virginiana L.	thimbleweed	3			X					1
Angelica atropurpurea L.	purplestem angelica	6						X		2
Apios americana Medik.	groundnut	3	X					X		2
Apocynum androsaemifolium L.	spreading dogbane	3				X	X		X	3
Apocynum cannabinum L.	Indian hemp	3	X	X	X					3
Arabidopsis thaliana (L.) Heynh.	mouse-ear cress	0		X				X		2
Arabis pycnocarpa M. Hopkins	hairy rock cress	6					X			1
Arctium minus Bernh.	common burdock	0				X	X			2
Arisaema dracontium (L.) Schott	green dragon	**8**		X	X	X	X			4
Arisaema triphyllum (L.) Schott	Jack-in-the-pulpit	5	X	X			X	X	X	5
Asarum canadense L.	wild ginger	5						X	X	2
Asclepias incarnata L.	swamp milkweed	6		X		X	X			3
Asclepias syriaca L.	common milkweed	1			X	X	X		X	4
Asimina triloba (L.) Dunal	pawpaw	**9**				X	X	X	X	4
Asplenium platyneuron (L.) D. C. Eaton	ebony spleenwort	2					X			1
Barbarea vulgaris R. Br.	yellow rocket	0	X	X		X	X	X		5
Berberis aquifolium Pursh	Oregon-grape	0							X	1
Berberis thunbergii DC.	Japanese barberry	0				X		X	X	3

(*Continued on next page*)

TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Bidens comosa (A. Gray) Wiegand	swamp tickseed	5						X		1
Boechera canadensis (L.) Al-Shehbaz	sickle-pod	7					X			1
Boechera laevigata (Willd.) Al-Shehbaz	smooth bank cress	5					X	X		2
Boehmeria cylindrica (L.) Sw.	false nettle	5	X	X	X	X	X	X	X	7
Bromus nottowayanus Fernald	satin brome	7					X	X		2
Bromus pubescens Willd.	Canada brome	5					X	X	X	3
Caltha palustris L.	marsh-marigold	6		X				X		2
Calystegia sepium (Kit.) Griseb.	false bindweed	0		X					X	2
Cardamine bulbosa (Muhl.) Britton, Sterns & Poggenb.	spring cress	4		X		X	X			3
Cardamine concatenata (Michx.) O. Schwarz	cut-leaved toothwort	5				X				1
Cardamine douglassii Britton	pink spring cress	6	X							1
Cardamine hirsuta L.	hoary bitter cress	0				X				1
Cardamine impatiens L.	bitter cress	0					X	X	X	3
Cardamine pensylvanica Willd.	Pennsylvania bitter cress	1	X							1
Carex albursina E. Sheld.	sedge	5				X				1
Carex amphibola Steud.	sedge	**8**		X				X		2
Carex aquatilis Wahlenb.	sedge	7					X			1
Carex bebbii (L. H. Bailey) Fernald	sedge	4		X	X	X	X			4
Carex blanda Dewey	sedge	1		X	X	X	X	X	X	6

Carex bromoides Willd.	sedge	6		X						1
Carex cephaloidea (Dewey) Dewey	sedge	5		X				X	X	3
Carex cephalophora Willd.	sedge	3						X		1
Carex crinita Lam.	sedge	4	X	X	X					3
Carex cristatella Britton										
Carex davisii	sedge Davis' sedge	3				X	X			2
Carex digitalis Willd.	sedge	5						X		1
Carex disperma Dewey	sedge	**10**					X			1
Carex echinodes (Fernald) P. Rothr., Reznicek & Hipp.	sedge	5		X			X	X	X	4
Carex emoryi Dewey	sedge	**7**				X				1
Carex gracilescens Steud.	sedge	5		X				X		2
Carex gracillima Schwein.	sedge	4	X		X	X	X			4
Carex granularis Willd.	sedge	2			X	X	X	X		4
Carex grayi J. Carey	sedge	6	X	X	X	X	X	X	X	7
Carex grisea Wahlenb.	sedge	3	X	X	X	X	X	X	X	7
Carex hirtifolia Mack.	sedge	5		X				X		2
Carex hystericina Willd.	sedge	2						X	X	2
Carex intumescens Rudge	sedge	3	X							1
Carex jamesii Schwein.	James' sedge	**8**				X				1
Carex lacustris Willd.	sedge	**6**						X		1
Carex laxiculmis Schwein.	sedge	**8**		X				X		2
Carex laxiflora Lam.	sedge	**8**		X				X		2
Carex lupulina Willd.	sedge	4		X	X	X	X		X	5

(*Continued on next page*)

TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Carex lurida Wahlenb.	sedge	3						X		1
Carex molesta Mack.	sedge	2					X	X		2
Carex normalis Mack.	sedge	5					X	X	X	3
Carex ormostachya Wiegand	sedge	5				X				1
Carex pensylvanica Lam.	sedge	4	X			X				2
Carex radiata (Wahlenb.) Small	straight-styled wood sedge	2	X		X	X	X	X	X	6
Carex retrorsa Schwein.	sedge	3		X						1
Carex rosea Willd.	curly-styled wood sedge	2		X				X	X	3
Carex scoparia Willd.	sedge	4					X			1
Carex sparganioides Willd.	sedge	5		X			X	X	X	4
Carex sprengelii Spreng.	sedge	5					X	X	X	3
Carex stipata Willd.	sedge	1	X	X		X	X	X	X	6
Carex stricta Lam.	sedge	4				X		X		2
Carex swanii (Fernald) Mack.	sedge	4				X	X	X		3
Carex tenera Dewey	sedge	4						X		1
Carex tribuloides Wahlenb.	sedge	3						X		1
***Carex trichocarpa* Willd. SC**	hairy-fruited sedge	**8**				X		X		2
Carex tuckermanii Dewey	sedge	**8**			X					1
Carex vulpinoidea Michx.	sedge	1		X		X	X	X	X	5
Carex woodii Dewey	sedge	**8**						X		1
Carpinus caroliniana Walter	hornbeam; blue-beech	6	X	X	X		X	X	X	6
Carya cordiformis (Wang.) K. Koch	bitternut hickory	5	X				X	X		3

Carya glabra (Mill.) Sweet	pignut hickory	5						X		1
Carya ovata (Mill.) K. Koch	shagbark hickory	5	X	X	X			X	X	5
Catalpa speciosa Warder	northern catalpa	0	X			X	X		X	4
Caulophyllum thalictroides (L.) Michx.	blue cohosh	5						X		1
Celastrus orbiculatus Thunb.	oriental bittersweet	0			X	X			X	3
Celtis occidentalis L.	hackberry	5	X			X	X	X	X	5
Centaurea stoebe L.	spotted knapweed	0				X				1
Cephalanthus occidentalis L.	buttonbush	7		X	X	X	X			4
Cerastium fontanum Baumg.	mouse-ear chickweed	0		X			X			2
Cerastium nutans Raf.	nodding chickweed	4					X			1
Cercis canadensis L.	redbud	**8**					X	X	X	3
Chasmanthium latifolium (Michx.) H. O. Yates	wild oats	0							X	1
Chelone glabra L.	turtlehead	7	X	X						2
Chrysosplenium americanum Hook.	golden saxifrage	6					X			1
Cicuta maculata L.	water hemlock	4	X	X	X	X				4
Cinna arundinacea L.	wood reedgrass	7		X	X		X	X		4
Circaea canadensis (L.) Hill	enchanters-nightshade	2		X	X	X	X	X	X	6
Cirsium arvense (L.) Scop.	Canada thistle	0			X	X	X		X	4
Cirsium muticum Michx.	swamp thistle	6						X		1
Cirsium vulgare (Savi) Ten.	bull thistle	0				X	X	X		3
Claytonia virginica L.	spring-beauty	4	X	X		X	X	X	X	6
Clematis virginiana L.	virgin's bower	4	X			X	X			3
Clinopodium vulgare L.	wild-basil	3					X			1

(*Continued on next page*)

TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Comarum palustre L.	marsh cinquefoil	7						X		1
Conopholis americana (L.) Wallr.	American cancer-root	**10**						X		1
Convallaria majalis L.	lily of the valley	0						X	X	2
Cornus alternifolia L. f.	alternate-leaved dogwood	5		X						1
Cornus amomum Mill.	silky dogwood	2				X				1
Cornus florida L.	flowering dogwood	**8**				X				1
Cornus foemina Mill.	gray dogwood	1	X		X					2
Cornus sericea L.	red-osier	2				X		X		2
Crataegus punctata Jacq.	dotted hawthorn	1	X				X	X		3
Crataegus succulenta Link	hawthorn	5					X			1
Cryptotaenia canadensis (L.) DC.	honewort	2	X	X	X		X	X	X	6
Cuscuta gronovii Roem. & Schult.	common dodder	3			X		X			2
Cynoglossum officinale L.	hound's tongue	0							X	1
Cystopteris bulbifera (L.) Bernh.	bulblet fern	5					X			1
Cystopteris protrusa (Wealth.) Blasdell	fragile fern	5					X			1
Cystopteris tenuis (Michx.) Desv.	fragile fern	5					X			1
Dactylis glomerata L.	orchard grass	0	X		X		X	X		4
Danthonia spicata (L.) Roem. & Schult.	poverty grass; oatgrass	4					X			1
Daucus carota L.	Queen Anne's lace	0				X				1
Dianthus armeria L.	Deptford pink	0						X		1
Diarrhena obovata (Gleason) Brandenburg	beak grass	9					X	X	X	3

Dichanthelium clandestinum (L.) Gould	panic grass	3						X	X	2
Dichanthelium implicatum (Scribn.) Kerguélen	panic grass	3	X							1
Dichanthelium latifolium (L.) Harvill	broad-leaved panic grass	5		X						1
Dichanthelium lindheimeri (Nash) Gould	panic grass	**8**					X			1
Digitaria sanguinalis (L.) Scop.	hairy crab grass	0						X		1
Dioscorea villosa L.	wild yam	4			X		X		X	3
Dipsacus fullonum L.	wild teasel	0				X				1
Dryopteris carthusiana (Vill.) H. P. Fuchs	spinulose woodfern	5	X	X			X	X		4
Echinochloa crusgalli (L.) P. Beauv.	barnyard grass	0					X	X		2
Echinocystis lobata (Michx.) Torr. & A. Gray	wild-cucumber	2	X							1
Elaeagnus umbellata Thunb.	autumn-olive	0	X		X	X	X	X		5
Elymus hystrix L.	bottlebrush grass	5		X			X	X		3
Elymus riparius Wiegand	riverbank wild-rye	**8**					X	X	X	3
Elymus villosus Willd.	silky wild-rye	5					X	X	X	3
Elymus virginicus L.	Virginia wild-rye	4	X	X	X	X	X	X	X	7
Enemion biternatum Raf.	false rue anemone	**8**	X	X		X			X	4
Epilobium parviflorum Schreb.	willow herb	0							X	1
Epipactis helleborine (L.) Crantz	helleborine	0					X	X	X	3
Equisetum arvense L.	common horsetail	0		X		X	X		X	4
Equisetum hyemale L.	scouring rush	2					X			1

(*Continued on next page*)

TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Equisetum laevigatum A.Braun	smooth scouring rush	2						X		1
Erigeron annuus (L.) Pers.	daisy fleabane	0	X	X	X	X	X	X		6
Erigeron philadelphicus L.	common fleabane	2	X		X					2
Erigeron strigosus Willd.	daisy fleabane	4					X			1
Erythronium albidum Ker Gawl.	white trout lily	7				X				1
Erythronium americanum Ker Gawl.	yellow trout lily	5	X	X		X				3
Euonymus alatus (Thunb.) Siebold	winged euonymus	0				X			X	2
***Euonymus atropurpureus* Jacq. - SC**	**wahoo, burning-bush**	**8**	X							1
Euonymus obovatus Nutt.	running strawberry-bush	5	X					X		2
Eupatorium perfoliatum L.	boneset	4						X		1
Eutrochium maculatum (L.) E. E. Lamont	Joe-pye-weed	4		X	X	X	X	X		5
Fagus grandifolia Ehrh.	American beech	6		X		X	X	X		4
Fallopia convolvulus (L.) Á. Löve	black bindweed	0	X			X		X		3
Festuca subverticillata (Pers.) E. B. Alexeev	nodding fescue	5		X				X		2
Festuca trachyphylla (Hack.) Krajina	sheep fescue	0							X	1
Ficaria verna Huds.	lesser celandine	0						X	X	2
Floerkea proserpinacoides Willd.	false mermaid	7		X					X	2
Fragaria virginiana Mill.	wild strawberry	2	X	X		X	X			4
Frangula alnus Mill.	glossy buckthorn	0	X							1

Fraxinus americana L.	white ash	5		X		X		X		3
Fraxinus nigra Marshall	black ash	6				X	X			2
Fraxinus pennsylvanica Marshall	red ash	2	X	X	X	X	X	X	X	7
Galium aparine L.	annual bedstraw	0	X	X	X	X		X	X	6
Galium asprellum Michx.	rough bedstraw	5						X		1
Galium circaezans Michx.	white wild licorice	4	X	X						2
Galium obtusum Bigelow	wild madder	5	X	X		X	X	X		5
Galium palustre L.	marsh bedstraw	3			X		X			2
Geranium maculatum L.	wild geranium	4	X	X			X	X		4
Geranium robertianum L.	herb Robert	3	X							1
Geum aleppicum Jacq.	yellow avens	3	X	X						2
Geum canadense Jacq.	white avens	1	X	X	X	X	X	X	X	7
Geum vernum (Raf.) T. & G.	spring avens	4	X	X		X				3
Glechoma hederacea L.	ground-ivy	0	X		X	X	X	X	X	6
Glyceria striata (Lam.) Hitchc.	fowl manna grass	4	X	X	X	X	X	X	X	7
Hackelia virginiana (L.) I. M. Johnst.	beggars lice	1			X	X	X	X	X	5
Hamamelis virginiana L.	witch-hazel	5		X					X	2
Heracleum maximum Bartram	cow-parsnip	3						X		1
Hesperis matronalis L.	dames rocket	0	X	X	X	X	X	X	X	7
Hieracium aurantiacum L.	orange hawkweed	0		X						1
Hieracium caespitosum Dumort.	king devil	0	X				X			2
Hydrophyllum canadense L.	Canada waterleaf	7		X						1
Hydrophyllum virginianum L.	Virginia waterleaf	4		X						1
Hylodesmum nudiflorum (L.) H. Ohashi & R. R. Mill	naked tick-trifoil	7						X		1

(*Continued on next page*)

TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Hypericum perforatum L.	common St. -ohns-wort	0					X			1
Hypericum prolificum L.	shrubby St. John's-wort	5			X					1
Hypericum punctatum Lam.	spotted St. John's-wort	4			X	X				2
Hypopitys monotropa Crantz	pinesap	6		X						1
Ilex verticillata (L.) A. Gray	Michigan holly	5						X		1
Impatiens capensis Meerb.	spotted touch-me-not	2	X	X	X	X	X	X		6
Iris pseudacorus L.	yellow flag	0		X			X	X		3
Iris virginica L.	southern blue flag	5	X	X	X	X	X	X		6
Juglans nigra L.	black walnut	5	X	X	X	X	X	X	X	7
Juncus dudleyi Wiegand	Dudleys rush	1					X	X		2
Juncus effusus L.	soft-stemmed rush	3					X	X		2
Juncus tenuis Willd.	path rush	1	X	X	X	X	X		X	6
Laportea canadensis (L.) Wedd.	wood nettle	4		X	X	X	X		X	5
Lapsana communis L.	nipplewort	0							X	1
Leersia oryzoides (L.) Sw.	cut grass	3	X			X	X			3
Leersia virginica Willd.	white grass	5	X		X	X	X		X	5
Lemna minor L.	common duckweed	5		X				X	X	3
Leonurus cardiaca L.	motherwort	0			X	X			X	3
Leucanthemum vulgare Lam.	ox-eye daisy	0				X			X	2
Ligustrum obtusifolium Siebold & Zucc.	border privet	0						X		1
Ligustrum vulgare L.	common privet	0							X	1
Lilium michiganense Farw.	Michigan lily	5		X				X		2

Lindera benzoin (L.) Blume	spicebush	7		X	X		X	X	X	5
***Lithospermum latifolium* Michx. - SC**	broadleaved puccoon	**10**						X		1
Lobelia cardinalis L.	cardinal-flower	7	X	X	X	X	X			5
Lobelia siphilitica L.	great blue lobelia	4		X						1
Lonicera ×bella Zabel	hybrid honeysuckle	0	X			X			X	3
Lonicera maackii (Rupr.) Herder	Armur honeysuckle	0						X		1
Lonicera morrowii A. Gray	Morrow honeysuckle	0				X		X	X	3
Lonicera tatarica L.	Tatarian honeysuckle	0						X		1
Ludwigia palustris (L.) Elliott	water-purslane	4					X			1
Luzula acuminata Raf.	hairy wood rush	5						X		1
Lycopus americanus Muhl.	common water horehound	2			X	X	X	X		4
Lycopus uniflorus Michx.	northern bugle weed	2					X			1
Lysimachia ciliata L.	fringed loosestrife	4		X	X	X	X	X		5
Lysimachia nummularia L.	moneywort	0		X	X	X	X	X	X	6
Lysimachia thyrsiflora L.	tufted loosestrife	6					X			1
Lythrum salicaria L.	purple loosestrife	0		X		X	X			3
Maianthemum canadense Desf.	Canada Mayflower	4					X			1
Maianthemum racemosum (L.) Link	false spikenard	5	X					X		2
Maianthemum stellatum (L.) Link	starry false Solomon-seal	5					X			1
Malus pumila Mill.	apple	0			X		X			2
Matteuccia struthiopteris (L) Todaro	ostrich fern	3						X	X	2
Medicago lupulina L.	black medick	0		X	X		X		X	4
Melilotus albus Medik.	white sweet-clover	0					X			1

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TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Melissa officinalis L.	lemon-balm	0							X	1
Menispermum canadense L.	moonseed	5	X	X	X			X		4
Mentha canadensis L.	wild mint	3				X	X		X	3
***Mertensia virginica* (L.) Pers. - E**	Virginia bluebells	**10**								3
Micranthes pensylvanica (L.) Haw.	swamp saxifrage	**10**						X		1
Mimulus ringens L.	monkey-flower	5				X	X	X	X	4
Moehringia lateriflora (L.) Fenzl	wood sandwort	5				X				1
Monarda fistulosa L.	wild-bergamot	2				X	X	X	X	4
Monotropa uniflora L.	Indian-pipe	5		X				X		2
Morus alba L.	white mulberry	0	X		X	X		X	X	5
Nasturtium officinale W. T. Aiton	watercress	0						X	X	2
Nepeta cataria L.	catnip	0							X	1
Onoclea sensibilis L.	sensitive fern	2		X	X		X	X	X	5
Osmorhiza claytonii (Michx.) C. B. Clarke	hairy sweet-cicely	4		X				X		2
Osmunda regalis L.	royal fern	5					X			1
Ostrya virginiana (Mill.) K. Koch.	ironwood; hop-hornbeam	5	X	X		X	X	X	X	6
Oxalis dillenii Jacq.	common yellow wood-sorrel	0		X				X	X	3
Oxalis stricta L.	yellow wood-sorrel	0			X	X	X		X	4
Packera aurea (L.) Á. Löve & D. Löve	golden ragwort	5			X		X			2
Parietaria pensylvanica Willd.	pellitory	2							X	1

Parthenocissus quinquefolia (L.) Planch.	Virginia creeper	5	X	X		X	X	X	X	6
Penstemon digitalis Nutt.	floxglove beard-tongue	2		X						1
Penthorum sedoides L.	ditch stonecrop	3					X			1
Persicaria hydropiperoides (Michx.) Small	mild water-pepper	5				X	X	X		3
Persicaria longiseta (Bruijn) Kitag.	creeping smartweed	0						X	X	2
Persicaria maculosa Gray	lady's-thumb	0				X	X	X		3
Persicaria punctata (Elliott) Small	smartweed	5				X			X	2
Persicaria sagittata (L.) H. Gross	arrow-leaved tear-thumb	5				X	X			2
Persicaria virginiana (L.) Gaertn.	jumpseed	4	X	X	X	X	X	X		6
Phalaris arundinacea L.	reed canary grass	0	X		X	X	X		X	5
Phellodendron amurense Rupr.	Amur cork-tree	0							X	1
Phlox divaricata L.	wild blue phlox	5					X	X		2
Phryma leptostachya L.	lopseed	4		X				X		2
Physalis heterophylla Nees	clammy ground-cherry	3					X			1
Physocarpus opulifolius (L.) Maxim.	ninebark	4						X	X	2
Phytolacca americana L.	pokeweed	2	X			X		X		3
Pilea pumila (L.) A. Gray	clearweed	5		X				X		2
Plantago major L.	common plantain	0			X	X	X			3
Plantago rugelii Decne.	red-stalked plantain	0		X						1
Platanus occidentalis L.	sycamore	7		X	X	X	X	X	X	6
Poa alsodes A. Gray	bluegrass	**9**						X		1
Poa compressa L.	Canadda bluegrass	0			X					1
Poa languida Hitchc.	bluegrass	6				X				1

(*Continued on next page*)

TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Poa palustris L.	fowl meadow grass	3					X	X	X	3
Poa pratensis L.	Kentucky bluegrass	0			X	X		X		3
Poa saltuensis Fernald & Wiegand	bluegrass	5				X				1
Poa sylvestris A. Gray	woodland bluegrass	8							X	1
Poa trivialis L.	bluegrass	0	X				X	X		3
Podophyllum peltatum L.	May-apple	3	X	X		X	X	X	X	6
Polygonatum biflorum (Walter) Elliott	Solomon-seal	4						X		1
Polystichum acrostichoides (Michx.) Schott.	Christmas fern	6						X		1
Populus deltoides Marshall	cottonwood	1	X	X		X	X	X	X	6
Potamogeton pusillus L.	small pondweed	4					X			1
Potentilla indica (Andrews) T. Wolf	Indian-strawberry	0						X	X	2
Potentilla recta L.	rough-fruited cinquefoil	0				X				1
Potentilla simplex Michx.	old-field cinquefoil	2	X							1
Proserpinaca palustris L.	mermaid-weed	6					X			1
Prunella vulgaris L.	self-heal	0			X	X	X	X	X	5
Prunus avium (L.) L.	sweet cherry	0						X		1
Prunus serotina Ehrh.	wild black cherry	2	X	X	X	X	X	X	X	7
Prunus virginiana L.	choke cherry	2	X	X					X	3
Ptelea trifoliata L.	hop-tree	4						X	X	2
Quercus alba L.	white oak	5		X				X	X	3
Quercus bicolor Willd.	swamp white oak	**8**	X	X	X	X	X	X	X	7

Quercus macrocarpa Michx.	bur oak	5	X	X	X	X	X		X	6
Quercus muehlenbergii Engelm.	chinquapin oak	5		X	X	X	X	X		5
Quercus rubra L.	red oak	5	X	X		X		X	X	5
Quercus velutina Lam.	black oak	5		X						1
Ranunculus abortivus L.	small-flowered buttercup	0		X						1
Ranunculus bulbosus L.	bulbous buttercup	0		X				X		2
Ranunculus hispidus Michx.	swamp buttercup	5	X	X	X	X	X	X		6
Ranunculus repens L.	creeping buttercup	0							X	1
Ranunculus sceleratus L.	cursed crowfoot	1					X			1
Rhamnus alnifolia L'Her.	alder-leaved buckthorn	8							X	1
Rhamnus cathartica L.	common buckthorn	0				X	X		X	3
Rhodotypos scandens (Thunb.) Makino	jetbead	0					X	X		2
Rhus glabra L.	smooth sumac	2		X						1
Rhus typhina L.	staghorn sumac	2				X				1
Ribes americanum Mill.	wild black currant	6		X	X		X			3
Ribes cynosbati L.	wild gooseberry	4		X	X	X		X	X	5
Robinia pseudoacacia L.	black locust	0			X					1
Rorippa palustris (L.) Besser	yellow cress	1				X	X			2
Rorippa sylvestris (L.) Besser	creeping yellow cress	0					X			1
Rosa multiflora Murray	multiflora rose	0		X	X	X	X	X	X	6
Rubus allegheniensis Porter	common blackberry	1		X	X	X	X			4
Rubus flagellaris Willd.	northern dewberry	1	X		X					2
Rubus occidentalis L.	black raspberry	1	X	X	X	X	X			5
Rubus pensilvanicus Poir.	dewberry	2					X			1
Rudbeckia hirta L.	black-eyed Susan	1		X						1

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TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Rudbeckia laciniata L.	cut-leaf coneflower	6		X		X				2
Rudbeckia triloba L.	three-lobed coneflower	5		X						1
Rumex crispus L.	curly dock	0	X		X	X	X		X	5
Rumex obtusifolius L.	bitter dock	0		X	X	X	X	X	X	6
Rumex verticillatus L.	water dock	7		X	X	X	X			4
Sagittaria cuneata E. Sheld.	arum-leaved arrowhead	6					X			1
Sagittaria latifolia Willd.	wapato, common arrowhead	4		X						1
Salix alba L.	white willow	0	X	X						2
Salix amygdaloides Andersson	peach-leaved willow	3	X						X	2
Salix discolor Muhl.	pussy willow	1				X				1
Salix eriocephala Michx.	willow	2		X						1
Salix exigua Nutt.	sandbar willow	1	X			X				2
Salix nigra Marshall	black willow	5				X				1
Salix sericea Marshall	silky willow	6	X					X		2
Sambucus canadensis L.	elderberry	3				X		X		2
Samolus parviflorus Raf.	water-pimpernel	5		X			X			2
Sanguinaria canadensis L.	bloodroot	5		X				X		2
Sanicula canadensis L.	black snakeroot	**8**				X				1
Sanicula odorata (Raf.) Pryer & Phillippe	black snakeroot	2		X			X	X		3
Saponaria officinalis L.	bouncing bet	0						X		1
Sassafras albidum (Nutt.) Nees	sassafras	5				X	X			2

Schoenoplectus tabernaemontani (C. C. Gmel.) Palla	softstem bulrush	4					X			1
Scirpus atrovirens Willd.	bulrush	3	X	X			X		X	4
Scirpus expansus Fernald	bulfush	5						X		1
Scirpus hattorianus Makino	mosquito bulrush	3					X			1
Scirpus pendulus Muhl.	bulrush	3	X							1
Scrophularia marilandica L.	late figwort	5					X		X	2
Scutellaria lateriflora L.	mad-dog skullcap	5		X	X		X	X		4
Silene latifolia Poir.	white campion	0	X				X		X	3
Sisyrinchium angustifolium Mill.	stout blue-eyed-grass	4		X	X		X	X	X	5
Sium suave Walter	water-parsnip	5					X			1
Smilax ecirrata (Kunth) S. Watson	upright carrion-flower	6						X		1
Smilax hispida Raf.	bristly greenbrier	5		X			X		X	3
Solanum carolinense L.	horse-nettle	0				X				1
Solanum dulcamara L.	bittersweet nightshade	0	X			X	X	X		4
Solanum ptychanthum Dunal	black nightshade	1						X	X	2
Solidago canadensis L.	Canada goldenrod	1	X	X		X				3
Solidago gigantea Aiton	late goldenrod	3		X	X		X			3
Sparganium eurycarpum Engelm.	common bur-reed	5	X				X			2
Sphenopholis intermedia (Rydb.) Rydb.	slender wedgegrass	4		X	X		X	X		4
Stachys hispida Pursh	hedge-nettle	5				X	X			2
Stachys tenuifolia Willd.	smooth hedge nettle	5						X		1
Staphylea trifolia L.	bladdernut	**9**			X			X	X	3
Symphyotrichum lateriflorum (L.) Á. Löve & D. Löve	calico aster	2						X		1

(*Continued on next page*)

TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Symphyotrichum novae-angliae (L.) G. L. Nesom	New England aster	3		X						1
Symphyotrichum ontarionis (Wiegand) G. L. Nesom	Lake Ontario aster	6		X						1
Symphyotrichum pilosum (Willd.) G. L. Nesom	hairy aster, frost aster	1						X		1
Symphyotrichum puniceum (L.) Á. Löve & D. Löve	swamp aster	5						X		1
Symplocarpus foetidus (L.) Nutt.	skunk-cabbage	6		X		X	X	X	X	5
Taraxacum officinale F. H. Wigg.	common dandelion	0	X		X	X	X			4
Teucrium canadense L.	wood-sage	4	X	X	X				X	4
Thalictrum dasycarpum Fisch. & Ave-Lall.	purple meadow-rue	3	X	X	X	X	X		X	6
Thalictrum dioicum L.	early meadow-rue	6		X		X		X		3
Thalictrum thalictroides (L.) Eames & B. Boivin	rue-anemone	8		X				X		2
Thelypteris noveboracensis (L.) Nieuwl.	New York fern	5					X			1
Thelypteris palustris Schott	marsh fern	2						X		1
Thuja occidentalis L.	white cedar	4				X				1
Tilia americana L.	basswood	5	X	X	X	X	X	X	X	7
Torilis japonica (Houtt.) DC.	hedge-parsley	0					X		X	2
Toxicodendron radicans (L.) Kuntze	poison-ivy	2	X	X	X	X	X	X	X	7
Tradescantia ohiensis Raf.	common spiderwort	5							X	1

Tragopogon pratensis L.	common goats beard	0			X		X	X		3
Trifolium hybridum L.	alsike clother	0			X					1
Trifolium repens L.	white clover	0			X	X	X			3
Trillium grandiflorum (Michx.) Salisb.	common trillium	5	X	X				X	X	4
Typha angustifolia L.	narrow-leaved cattail	0				X				1
Ulmus americana L.	American elm	1	X	X	X	X	X	X	X	7
Urtica dioica L.	stinging nettle	1	X	X	X	X	X	X	X	7
Uvularia grandiflora Sm.	bellwort	5						X		1
Verbascum blattaria L.	moth mullein	0					X			1
Verbascum densiflorum Bertol.	mullein	0					X			1
Verbascum thapsus L.	common mullein	0				X	X		X	3
Verbena urticifolia L.	white vervain	4	X	X	X	X	X	X	X	7
Vernonia missurica Raf.	Missouri ironweed	4			X	X	X			3
Veronica hederifolia L.	ivy-leaved speedwell	0							X	1
Veronica serpyllifolia L.	thyme-leaved veronica	0				X				1
Viburnum acerifolium L.	maple-leaved viburnum	6		X		X				2
Viburnum lentago L.	nannyberry	4			X			X		2
Viburnum opulus L.	European highbush-cranberry	0				X				1
Viburnum plicatum Thunb.	Japanese snowball	0						X		1
Viburnum trilobum Marshall	American high-bush-cranberry	5		X						1
Vinca minor L.	periwinkle	0							X	1
Vincetoxicum nigrum (L.) Pers.	black swallow-wort	0			X				X	2
Viola canadensis L.	Canada violet	5		X				X		2

(*Continued on next page*)

TABLE 3. (*Continued*)

Species	Common Name	*C*-Value	Crystal Springs	Paris Park	Wernlund Property	Covenant Park	Stanaback Park	Ken-O-Sha Park	Madison Ave.	Number of Sites
Viola cucullata Aiton	marsh violet	5					X			1
Viola pubescens Aiton	yellow violet	4		X		X	X		X	4
Viola sororia Willd.	common blue violet	1	X	X		X	X	X	X	6
Viola striata Aiton	cream violet	5	X	X	X	X	X	X	X	7
Vitis aestivalis Michx.	summer grape	6					X			1
Vitis riparia Michx.	river-bank grape	3	X	X	X	X	X	X	X	7
Zanthoxylum americanum Mill.	prickly ash	3	X		X			X		3
Total number of species/site			**115**	**164**	**118**	**172**	**215**	**215**	**154**	

FIGURE 4. Plaster Creek floodplain at Covenant Park, Kentwood. Image source: Google Earth, 2009.

lily (*E. albidum*), wood sandwort (*Moehringia lateriflora*), May-apple (*Podophyllum peltatum*), skunk cabbage (*Symplocarpus foetidus*), two species of meadow-rue (*Thalictrum dasycarpum* and *T. dioicum*), and three species of violets (*Viola pubescens, V. sororia*, and *V. striata*).

Several species in this remnant site are noteworthy, based on records from MICHIGAN FLORA ONLINE (2011). In early spring, several large patches of the less commonly seen white trout lily (*Erythronium albidum*) were encountered. Water dock (*Rumex verticillatus*) was found in abundance, despite having not been documented in the Grand Rapids area since Emma Cole's collections in 1896 (Jenison, Ottawa County) and 1897 (Grand Rapids Township, Kent Co.). Our documentation of black snakeroot (*Sanicula canadensis*) represents a new county record for Kent County. Of the 19 sedge species (*Carex* spp.), three are especially notable: James' sedge (*Carex jamesii*), a clump-forming species characteristic of rich moist forests that had been documented only twice in Kent County prior to the Emma Cole Grand Rapids Flora Project; Emory's sedge (*Carex emoryi*), an uncommon sedge of riverbanks, had not been documented for Kent County since Emma Cole collected it in 1897 (at the Plaster Creek Crystal Springs site), and *Carex davisii*, a species only known locally from five river systems of southern Michigan (Clinton, Grand, Raisin, Rouge, and St. Joseph River systems) (MICHIGAN FLORA ONLINE 2011).

While it is remarkable that the intact remnant forested parcels have, collectively, retained a rather high FQA, we regret that much of the natural floodplain has been converted into fairways. Now that this large parcel is a public park, it would be desirable not only to preserve the remaining natural areas but to enhance their ecological quality and repair what has been damaged. We encourage

FIGURE 5. Plaster Creek floodplain in Stanaback Park Area, Kentwood. Image source: Google Earth, 2021.

Kentwood Parks and Recreation to consider restoring the presently unused fairways into more functional, biodiverse floodplain habitats, which would connect the isolated remnants into a much larger and more functional ecosystem.

Stanaback Park (42° 53.800'N, 85° 35.945'W)

A total of 215 species, of which 80.9% are native, were recorded in this large floodplain (Figure 5). The Floristic Quality Assessment (Table 2) showed a Total FQI of 48.4 and a Native FQI of 52.8, the second highest FQIs of all the sites studied—indicative of extraordinarily high quality, and a significant component of Michigan's remaining native biodiversity—making this site especially worthy of protection (Table 1). The Total Mean *C* for this site (3.3) was intermediate among the seven sites inventoried (Table 1), yet several species have high-fidelity *C*-values of *C*-8–*C*-10: green dragon (*Arisaema dracontium*), *C*-8; pawpaw (*Asimina triloba*), *C*-9; sedge (*Carex disperma*), *C*-10; redbud (*Cercis canadensis*), *C*-8; panic grass (*Dichanthelium lindheimeri*), *C*-9; riverbank wildrye (*Elymus riparius*), *C*-8; and swamp white oak (*Quercus bicolor*), *C*-8.

The Plaster Creek floodplain in Stanaback Park has an open forest cover and supports 26 different native trees species, including many mature specimens. Among these are four species of maples (*Acer saccharum*, *A. nigrum*, *A. saccharinum*, *A. negundo*), pawpaw (*Asimina triloba*), hornbeam (*Carpinus caroliniana*), redbud (*Cercis canadensis*), two hawthorns (*Crataegus succulenta* and *C. punctata*), American beech (*Fagus grandifolia*), two species of young ash trees (*Fraxinus nigra, F. pennsylvanica*), black walnut (*Juglans nigra*), ironwood (*Ostrya virginiana*), sycamore (*Platanus occidentalis*), three species of oaks (*Quercus bicolor*, *Q. macrocarpa*, *Q. muehlenbergii*), sassafras (*Sassafras albidum*), and basswood (*Tilia americana*).

This site has perhaps the most impressive population of sycamore trees in the Grand Rapids area, a species typically found along rivers and streams in southern Michigan and states farther to the south. An especially noteworthy feature of this floodplain is that high in the treetops of one cluster of very large sycamores

is a magnificent rookery of Great Blue Herons, consisting of about 20 nests (Figure 8).

Of the 8 shrub species present in the Stanaback Park floodplain, six are native, including buttonbush (*Cephalanthus occidentalis*), spicebush (*Lindera benzoin*), wild black currant (*Ribes americanum*) and three species of blackberry/raspberry (*Rubus allegheniensis*, *R. occidentalis* and *R. pensilvanicus*). Unhappily, two notoriously invasive non-native shrubs, autumn olive (*Elaeagnus umbellata*) and multiflora rose (*Rosa multiflora*), are widespread and common throughout the floodplain, the latter forming dense thickets in some noticeably disturbed areas.

The floodplain also supports a wealth of graminoids, including 20 species of grasses, 23 species of sedges, and three species of rushes. As a group, sedges make up an important component of Michigan's native biodiversity, especially in wetland ecosystems like floodplains. All sedge species found growing at this site are native, and a few are of high-fidelity *C*-value. *Carex disperma* (*C*-10) has only been collected three times in Kent County, most recently in 1940; and *Carex aquatilis*, a wetland sedge (*C*-7), also had not been documented in Kent County since 1941 (MICHIGAN FLORA ONLINE 2011). Other distinctive sedges found at the site include *Carex grayi*, *C. lupulina*, *C. gracilescens*, and *C. echinodes*.

Several of the 20 species of grasses found in this floodplain have high *C*-values, as well. Panic grass (*Dichanthelium lindheimeri*) and riverbank wild-rye (*Elymus riparius*), both *C*-8, and wood reedgrass (*Cinna arundinacea*) and satin brome (*Bromus nottowayanus*), both *C*-7, were all documented in the floodplain. Over half of the species documented at the site are herbaceous. In fact, the floodplain supports an impressive 127 species of herbaceous plants, many with attractive flowers, and 46 species of graminoids. Numerous notable floodplain natives were found here, including green dragon (*Arisaema dracontium*), swamp milkweed (*Asclepias incarnata*), golden saxifrage (*Chrysosplenium americanum*)—which had not been collected along Plaster Creek since 1896, and not previously documented in Kent County since 1919 (MICHIGAN FLORA ONLINE 2011)—southern blue flag (*Iris virginica*), cardinal flower (*Lobelia cardinalis*), mermaid weed (*Proserpinaca palustris*), water dock (*Rumex verticillatus*), arum-leaved arrowhead (*Sagittaria cuneata*), water parsnip (*Sium suave*), common bur reed (*Sparganium eurycarpum*), skunk cabbage (*Symplocarpus foetidus*), and four species of violets (*Viola cucullata*, *V. pubescens*, *V. sororia*, *V. striata*).

Ken-O-Sha Park (42° 54.397'N, 85° 38.165'W)

A total of 214 species, of which 82.2% are native, were recorded along Plaster Creek at Ken-O-Sha Park (Figure 6). This site is on par with Stanaback Park as having the highest species richness. The Floristic Quality Assessment (Table 2) showed a Total FQI of 52.7 and a Native FQI of 58.4. These FQI values were the highest of the seven sites surveyed, exceeding the FQI threshold of greater than 50 (Table 1), indicating that the site exhibits extremely high conservation value and represents a significant component of Michigan's native biodiversity

FIGURE 6. Plaster Creek floodplain at Ken-O-Sha Park, Kalamazoo Ave., Grand Rapids. Image source: Google Earth, Maxar Technologies, image April, 2019.

and natural landscapes. While Ken-O-Sha boasts the highest FQIs of all sites, its Total Mean *C* of 3.6 is slightly lower than Paris Park's Total Mean *C* of 3.7 and slightly higher than Stanaback Park's Total Mean *C* of 3.3 (Table 2). Goforth et al. (2001) and Herman et al. (2001) do not find it unusual for sites with similar FQIs to have rather different Mean *C*-values. Of the 176 native species, more species with high-fidelity *C*-values (*C*-8–*C*-10) occur in this floodplain site than in any of the others. These include pawpaw (*Asimina triloba*), *C*-9; 5 species of sedges (*Carex amphibola*, *C*-8; *C. laxiculmus*, *C*-8; *C. laxiflora*, *C*-8; *C. trichocarpa*, *C*-8, *C. woodii*, C-8), redbud (*Cercis canadensis*), *C*-8; American cancer-root (*Conopholis americana*), *C*-10; riverbank wild-rye (*Elymus riparius*), *C*-8; swamp saxifrage (*Micranthes pensylvanica*), *C*-10; bluegrass (*Poa alsodes*), *C*-9; swamp white oak (*Quercus bicolor*), *C*-8; bladdernut (*Staphylea trifolia*); *C*-9; and rue-anemone (*Thalictrum thalictroides*), *C*-8.

The floodplain forest in this site supports 29 tree species. Black maple (*Acer nigrum*) is predominant, and boxelder (*A. negundo*), red maple (*A. rubrum*), silver maple (*A. saccharinum*) and sugar maple (*A. saccharum*) are common. Other trees that are present, but usually widely scattered and not in abundance, include bitternut hickory (*Carya cordiformis*), shagbark hickory (*C. ovata*) and pignut hickory (*C. glabra*), black ash (*Fraxinus pennsylvanica*), hackberry (*Celtis occidentalis*), black walnut (*Juglans nigra*), sycamore (*Platanus occidentalis*), swamp white oak (*Quercus bicolor*), white oak (*Q. alba*), red oak (*Q. rubra*), black cherry (*Prunus serotina*), cottonwood (*Populus deltoides*) and American elm (*Ulmus americana*). The understory layer is occupied by redbud (*Cercis canadensis*), hornbeam (*Carpinus caroliniana*), hop-hornbeam (*Ostrya virginiana*), spicebush (*Lindera benzoin*), and bladdernut (*Staphylea trifoliata*). Dotted hawthorn (*Crataegus punctata*) was sparse and scattered at this site, although

just upstream at the Stanaback Park floodplain it is locally abundant, forming small groves.

A well-used asphalt walking trail begins at the parking area of the Ken-O-Sha Elementary School and parallels Plaster Creek along the length of Ken-O-Sha Park downstream, giving the general public access to experience the beauty of the rich deciduous beech-maple woods with frequent views into the lower floodplain. In spite of its heavy usage, the trail largely avoids the floodplain, thereby minimizing disturbance and helping to preserve the quality of the floodplain in this park. Yet the floodplain remains vulnerable to adventive and sometimes aggressive non-native species. This is one of only two localities where scattered plants of the ornamental shrub jetbead (*Rhodotypus scandens*) have become established. Likewise, the adventive Indian-strawberry (*Potentilla indica*) is known only from this site and the Madison Avenue Crossing site, which is just downstream. The recently spreading bitter cress (*Cardamine impatiens*) is common here; it has been noted by Voss and Reznicek (2012) as "A rapid invader of forest understories," although it is currently known from only five counties in Michigan. Another adventive documented in only five Michigan counties, but abundant at this site in early spring, is lesser celandine (*Ficaria verna*).

Madison Avenue (42° 54.995'N, 85° 39.215'W)

A total of 153 species, of which 71.9% are native, were recorded at the small floodplain of Plaster Creek where it crosses Madison Avenue, along Plaster Creek Trail (Figure 7). This is the most urban floodplain among the seven we inventoried. The Floristic Quality Assessment (Table 1) showed a Total FQI of 34.6 and a Native FQI of 42.0 for this site. Its Total Mean *C* of 2.8 matched that of the small floodplain on the Wernlund Property, and is the lowest Total Mean *C* of the seven study sites; the Crystal Springs and Covenant Park sites have only a slightly higher Total Mean *C* of 2.9. A rather disturbed site, the Madison

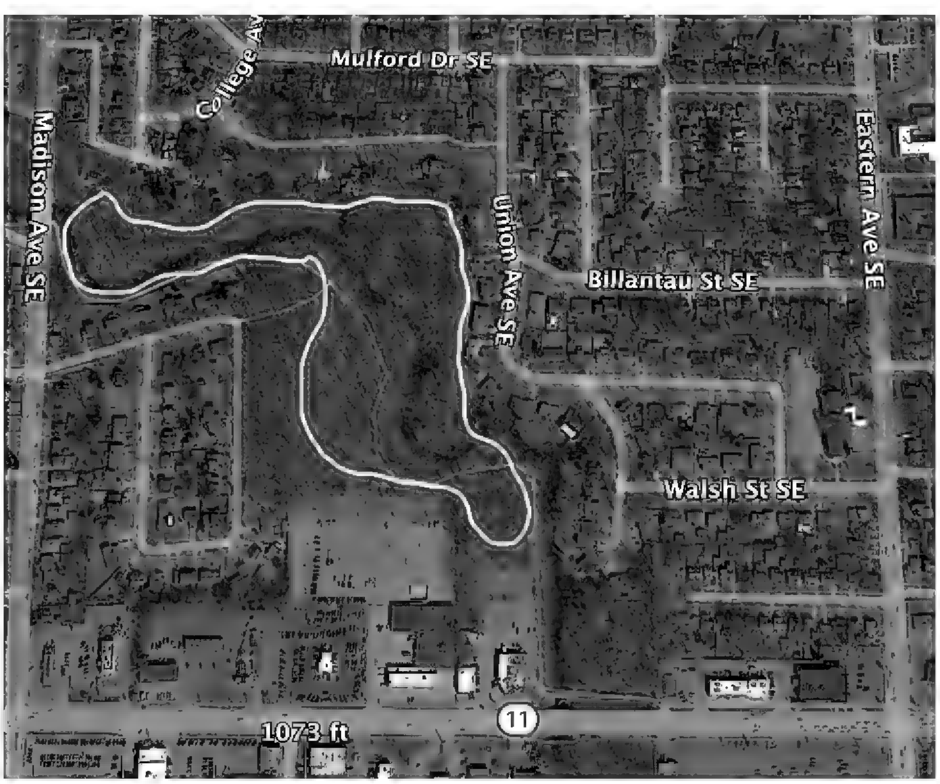

FIGURE 7. Plaster Creek floodplain at Madison Ave. Crossing, Grand Rapids. Image source: Google Earth, March 2021.

Avenue floodplain also ranked highest in percentage of non-natives (28.1%, 43 species). However, the north side of the creek—the least accessible portion of the floodplain—is far less disturbed and supports a very robust population of a rare graminoid, beak grass (*Diarrhena obovata*), with a high-fidelity *C*-value (*C*-9). This is also the site where our showy native redbud (*Cercis canadensis*), *C*-9, is best represented—a species Emma Cole (1901) noted as reaching its geographic northern limit along the Grand River within the Grand Rapids region. Another *C*-9 species, bladdernut (*Staphylea trifolia*), was also found here. Three additional high-fidelity *C*-value species encountered at this site include riverbank wild-rye (*Elymus riparius*), *C*-8; false rue anemone (*Enemion biternatum*), *C*-8; and swamp white oak (*Quercus bicolor*), *C*-8.

In sharp contrast to the high-value native species, garden escapes also appear in some of these natural-looking habitats. Wild-oats (*Chasmanthium latifolium*), an attractive and often cultivated grass species, was documented at the Madison Avenue crossing. This species is listed as native and Endangered in Michigan, but Voss and Reznicek (2012) state that while it is indeed native along the floodplain of the Galien River in Warren Woods, Berrien County, all Michigan records outside Berrien County are regarded as escapes from cultivation. Another escape from cultivation we encountered is a cluster of several small trees of the rutaceous Amur cork-tree (*Phellodendron amurense*). A third noteworthy adventive species at this site is lemon-balm (*Melissa officinalis*). Often cultivated for its aromatic oils, lemon-balm is seldom known as an escape, and our documentation is the first record for Kent County and sixth county documentation for the state (MICHIGAN FLORA ONLINE 2011). Black swallow-wort (*Vincetoxicm nigrum*), an aggressive weed that appears in many localities in Michigan, was collected here and in several other sites inventoried by the Emma Cole Grand Rapids Flora Project, but it has not yet appeared for Kent County on the MICHIGAN FLORA ONLINE (2011) website maps. We collected ivy-leaved speedwell (*Veronica hederifolia*), which was not reported for Michigan until 1999, and but now known from seven sites in five counties (MICHIGAN FLORA ONLINE 2011); ours was the second collection from Kent County, the first having been collected along Plaster Creek in 2015 (*Slaughter 1393* MICH) just one mile downstream from our site.

The Madison Avenue floodplain is yet another Plaster Creek site that directly connects our study with Emma Cole's work. Cole (1901) mentions several plants from along Plaster Creek "at Madison Ave.," although many of these are species of drier habitats and likely occurred along the high banks and bluffs of Plaster Creek. Ironically, while we report *Veronica hederifolia* as a relatively new adventive to Michigan, Emma Cole's first encounter with *Vernonica hederifolia* was made on her four-month trip to Europe at Cave Hill, Belfast, Ireland, July 9, 1903 (*Cole 51703* MICH), two years after the publication of her *Grand Rapids Flora* (Cole 1901).

Plaster Creek in the 1890s Compared to Today

A search of all Plaster Creek entries in Emma Cole's (1901) *Grand Rapids Flora* was conducted, as well as a search of the MICHIGAN FLORA ONLINE

(2011) database for Cole's specimens collected along Plaster Creek, yielding 84 species. Although Cole did not always indicate specifically where along Plaster Creek her specimens were collected, it is reasonable to treat the whole of Plaster Creek as a single entity. However, a number of those species indicated as "Plaster Creek" were clearly not wetland plants, such as prairie smoke (*Geum triflorum*) and kitten-tail (*Besseya bullii*). Therefore, after removing Cole's plants that clearly grow in dry sites, a total of 65 species were included in the Floristic Quality Assessment carried out for the 1890s material. Some of Cole's records, such as showy lady-slipper (*Cypripedium reginae*), tawny cotton-grass (*Eriophorum virginicum*), and queen-of-the-prairie (*Filipendula rubra*) are likely to have occurred in fen-like seeps either immediately at the interface of floodplain with the base of ravines, or possibly seeps higher up on the banks of Plaster Creek. We have retained these species in our analysis because we also included such habitats in our inventories.

The 1890s Floristic Quality Assessment includes 98.5% (64 species) native species and only 1.5% (1 species) non-native. The Total FQI was 48.4 for this collection of species, and the Native FQI was 48.8; the Total Mean *C* was a robust 6.0. A total of 27 species had a high *C*-value of 8–10 (8 species with 10, 9 species with 9, and 10 species with 8) (Table 4).

The 40.6% of native species with high *C*-values from Cole's list (26 of 64) is markedly higher than our present-day tally of only 7.9% (27 of 341) based on the combined Plaster Creek flora for the seven sites (Table 3). Furthermore, we were unable to locate 19 of the 27 species on Cole's Plaster Creek list with C-values of 8–10. Although there had been no assigned *C*-values back in Emma Cole's day, this comparison shows that many species that require undisturbed habitats are no longer present in our floodplain sites, despite Emma Cole's work confirming that they once existed there. It is also notable that only 1.5% of the species on Cole's list (1 of 65) were non-natives, which is markedly smaller than our sites, for which non-native species constitute 22.1% of the total number of plants documented (97 of 438).

While the loss of species reflected in these data is deeply regretful, it was encouraging to find several relatively rare species (locally and state-wide) persisting in these floodplains. For example, green dragon (*Arisaema dracontium*) had not been documented in Kent County since the late 1800s—twice by Emma Cole—yet we found it in four of our seven sites. We also found golden saxifrage (*Chrysosplenium americanum*), a species that had been documented only once, in 1939, since Emma Cole's day, in the Stanaback floodplain. In addition, the state threatened Virginia bluebells (*Mertensia virginica*) is still thriving in multiple floodplain sites along Plaster Creek today. So, although several species appear to have been lost from our landscape over the past 120+ years, there remains a good amount of native Michigan biodiversity, even in urban greenspaces, that will benefit from sound preservation, conservation, and restoration efforts.

It must be noted that Emma Cole's purpose in cataloging the 1275 species recorded in her *Grand Rapids Flora* (Cole 1901) was quite different from our effort to conduct full inventories of numerous high-value natural landscapes within the area covered by Cole. Her collections along Plaster Creek were not meant to

TABLE 4. Species having a *C*-value of 8–10, indicating a high level of fidelity to a narrow range of undisturbed ecological conditions, among those collected and reported by Emma Cole from along Plaster Creek and those collected in the current study. An X indicates the presence of a species in each case. The state status of listed species, which are in boldface, is indicated as follows: E = Endangered; T = Threatened; SC = Special Concern.

Species	State Listing Status	*C*-Value	Emma Cole 1890s	Current Study
Carex disperma		10		X
Carex prairea		10	X	
Carex stipata		10	X	
Conioselinum chinense		10	X	
Conopholis americana		10		X
Filipendula rubra	**T**	10	X	
Hypericum kalmianum		10	X	
Lithospermum latifolium	**SC**	10		X
Lysimachia quadriflora		10	X	
Mertensia virginica	**E**	10	X	X
Micranthes pensylvanica		10		X
Trillium nivale	**T**	10	X	
Asimina triloba		9	X	X
Carex tetanica		9	X	
Cypripedium reginae		9	X	
Diarrhena obovata		9		X
Deschampsia cespitosa		9	X	
Jeffersonia diphylla	**SC**	9	X	
Morus rubra	**T**	9	X	
Poa alsodes		9		X
Rumex orbiculatus		9	X	
Salix candida		9	X	
Salix myricoides		9	X	
Staphylea trifolia		9		X
Arisaema dracontium		8	X	X
Carex amphibola		8		X
Carex jamesii		8		X
Carex laxiculmis		8		X
Carex laxiflora		8	X	X
Carex trichocarpa	**SC**	8		X
Carex tuckermanii		8		X
Carex woodii		8	X	X
Cercis canadensis		8	X	X
Chaerophyllum procumbens		8	X	
Cornus florida		8		X
Dichanthelium lindheimeri		8		X
Elymus riparius		8		X
Enemion biternatum		8		X
Eriophorum virginicum		8	X	
Euonymus atropurpureus	**SC**	8		X
Menyanthes trifoliata		8	X	
Orobanche uniflora		8	X	
Poa sylvestris		8		X
Quercus bicolor		8		X
Rhamnus alnifolia		8		X
Sanicula canadensis		8		X
Valerianella chenopodiifolia		8	X	
TOTALS	**8**		**25**	**27**

FIGURE 8. Left: Tall sycamore trees with Great Blue Heron rookery. Right: Great Blue Heron on nest. May 18, 2021. Photos by Garrett E. Crow.

fully capture the floristic composition of the floodplain. Yet, Cole's documentation of 65 wetland species from the 1890s, though representing but a fraction of the actual Plaster Creek corridor flora, still provides a sense of the scope of change that has taken place across the Plaster Creek landscape since Emma Cole was botanizing this landscape.

Rare Plants (Past and Present)

Table 4 lists all species documented in the present study as well as those documented by Emma Cole in the 1890s from Plaster Creek that have a high level of fidelity to a narrow range of undisturbed ecological conditions, that is, those with *C*-values in the range 8–10, and also highlights those species that are listed by the Michigan Natural Features Inventory (MNFI 2009, updated March 2023) with a state status of Endangered (E), Threatened (T), or Special Concern (SC). Because of the sensitivity of any state-listed species that are threatened or endangered, we have withheld their locality data. In the following enumeration of these species, information regarding their broader occurrence in Michigan is drawn from the MNFI online database (available at https://mnfi.anr.msu.edu/species/plants).

Mertensia virginica (Virginia bluebells): Threatened. State-wide, this beautiful species is documented by 25 occurrences in 11 counties, including seven from Kent County (MNFI 2023). We found this plant growing in three of our floodplain sites, ranging from very sparse to robust populations (Figure 9).

FIGURE 9. Bottom left: Robust population of *Mertensia virginica*. Bottom right: *Mertensia virginica* flowering. May 7, 2021. Photos by Garrett E. Crow.

Emma Cole (1901) described it as "scarce" and as occurring in rich alluvial soil in scattered sites along the Grand River, Plaster Creek, and in woods within Byron Township. At the time of our study, this species was listed as Endangered (MNFI 2009), but as of March 20, 2023, the status was changed to Threatened (MNIF 2023).

Diarrhena obovata (beak grass): Formerly Threatened, now delisted. This species is documented as having 40 occurrences in 17 counties in Michigan, including three in Kent County (as of 2016) (MNFI 2009). At the time of this study, the species was listed as Threatened status (MNFI 2009), but has since been delisted by MNFI (2023). This species was not recorded by Cole (1901). We encountered *Diarrhena obovata* at three sites along the Plaster Creek floodplain, all with very robust populations; the size of the existing populations appears to be increasing. The robustness of populations we observed concurs with the assessment by MNFI (2023) to delist this species.

Filipendula rubra (Hill) B. L. Rob. (Queen-of-the-prairie): Threatened. A plant of wet prairies, fens and wet meadows with showy pink feathery panicles is documented as having 22 occurrences in six counties, but not in Kent County (MNFI 2023). Although we did not encounter this attractive species in our study, we have collected it at a wet meadow in Ada Township. Emma Cole (1901) referred to this species as *Spiraea lobata* Jacq. (Crow 2017). She considered it "rare," citing only two populations, but she also noted that the species is often seen in cultivation. Voss and Reznick (2012) likewise note that the species is sometimes cultivated, regarding it native in Calhoun, Cass, Berrien and possibly

Kent Counties, yet suggesting that even in those counties there may be populations that originated as escapes from cultivation.

Morus rubra L. (red mulberry): Threatened. A small tree of river bottoms, floodplains and swamps, red mulberry has been documented 42 times in 16 counties (MNFI 2023). We have not encountered this species despite numerous visits to habitats where it might be expected, including a visit to a particular location on the Grand River where it was documented by Emma Cole. Cole (1901) indicated that red mulberry populations were all in alluvial soil, but only "occasional" in occurrence. She cites "Plaster Creek" as well as localities along the Grand River as supporting this species.

Trillium nivale Riddell (snow trillium): Threatened. Snow trillium has been documented in ten localities within four counties in Michigan (MNFI 2023). Cole (1901) reported it as "rare; north bank of Plaster Creek" as well as at four other sites; four later collections document it from Kent County in MICHIGAN FLORA ONLINE (2011). Once known from the floodplain at Paris Township (now Ken-O-Sha Park, Grand Rapids), the species was last documented by two specimens collected by different botanists in 1939 (Reznicek, pers. comm.). Despite its historic presence along Plaster Creek, we did not encounter this species in our study. A story has circulated that, after having been shown this rare but beautiful plant on a class field trip, all students turned in their required plant collection projects—each having a specimen of *Trillium nivale*—resulting in the decimation of that population (as related by E. G. Voss in 1982 to Robert Bloye, pers. comm.).

Carex trichocarpa (hairy-fruited sedge): Special Concern. Occurrences of this rhizomatous, clonal sedge of riparian wetlands with characteristic reddish leaf bases have been documented from 21 localities in 9 counties, the most recent from Kent County in 1939 (MNFI 2009, 2023). In 2015, Warners spotted it along a creek at the edge of a golf course (*Leisman, Van Staalduinen and Warners EC-15-319* CALVIN) that ultimately empties into Plaster Creek; he again discovered it at two of the floodplain sites of this study, Covenant Park and Ken-O-Sha Park. Interestingly, Cole's (1901) recording of *C. trichocarpa* in her *Grand Rapids Flora* was based on a mis-determination of *C. lupulina* (Crow 2017).

Euonymus atropurpureus (wahoo or burning-bush): Special Concern. Occurrences of wahoo, an understory tree or tall shrub that is most easily recognized in fall by the presence of nodding pink capsules that dehisce to reveal seeds surrounded by a red fleshy aril is documented at 30 localities in 12 counties (MNFI 2009, 2023). Crow stumbled onto a single individual along Plaster Creek at the Crystal Springs site in the fall of 2022 (*Crow 11181*, CALVIN, MICH, MSC). According to MICHIGAN FLORA ONLINE (2011), the species had not been documented from Kent County since Emma Cole's collections in 1896. The Emma Cole Grand Rapids Flora Project collected this species in 2017 in Ottawa County in one of the many ravines along the Grand River (*Van Donselaar, Antuma, & Quakenbush EC-17-2200*, CALVIN). Cole (1901) stated that this species was known from Ottawa County along the Grand River at West Bridge Street Ferry, at Boynton's Landing, and at church picnic grounds in Jenison in Ottawa County. She also noted that in Kent County it occurred along the Grand

River in Plainfield Village and in woods south of Reeds Lake. Cole reported that it was "formerly frequent, but it has been dug up and sold for medicinal purposes; now it is chiefly found in unfrequented places."

Jeffersonia diphylla (L.) Pers. (twinleaf): Special Concern. Occurrences of twinleaf, an herb of rich woods and floodplains with a distinctive pair of stem leaves and petals that readily drop off soon after flowering (i.e., caducous), is documented from 34 occurrences in 16 counties (MNFI 2023). Emma Cole (1901) characterized twinleaf as "rare," growing in rich moist woods; she added that in the 1870s "it grew along Plaster Creek, south of Hall St." We did not encounter this distinctive species during our study of Plaster Creek floodplains but did collect it in 2019 in a rich woods in Byron Township, Kent County (*Walt, Hartwig & Crow EC-19-4000*, CALVIN, MICH).

Lithospermum latifolium (broad-leaved puccoon): Special Concern. Statewide occurrences of this species have been documented from 29 localities in 12 counties (MNFI 2009, 2023). It was encountered at only a single floodplain, Ken-O-Sha Park, in this study; however, we have otherwise documented it from three additional sites in Kent County (Stockdale et al., 2019; Warners et al. 2021). This species typically occurs in floodplain forests or rich ravines, where we have found it to be sparsely scattered. Although Cole (1901) did not specifically record this plant from Plaster Creek, she noted that it was "[F]requent on the edges of woods."

CONCLUDING REMARKS

A close look at our seven sites reveals that even though all seven floodplain areas are within the same drainage basin, only 6.2% of the species we identified (27 of 438) were found in all seven floodplains (Table 3). By contrast, 39.7% (174 species) were found in only one site, a number that is remarkably similar to a comparison made among the inventories of nine forest remnants within a one square mile area in Lowell Township, Kent County (Warners et al. 2021). In that study, 37% of the total number of species were found in only one of the nine woodlots. These comparisons highlight that within the same habitat type and even within a very limited geographic zone, individual natural areas can harbor remarkably different species assemblages. More specifically, floodplain habitats within a single watershed can be dramatically dissimilar. Recognizing such diversity within habitat types highlights the importance of protecting and caring for every parcel of high-quality natural habitat that remains in human-dominated landscapes.

Although each site does harbor a valuable and unique assemblage of Michigan's native floodplain flora, three of the seven sites we inventoried—the floodplains at Ken-O-Sha Park, Stanaback Park, and Paris Park—stand out. All three have high FQIs, and each represents a significant component of Michigan's remaining native biodiversity (Tables 1 and 2). The floodplain at Stanaback Park is especially valuable given its impressive size for an urban natural area (nearly 22 hectares) and because it is relatively well-protected by surrounding wood-

FIGURE 10. Floodplain restoration in process at Crystal Springs site located at the Leisure Creek Condominium Association. May 6, 2022. Photo by David P. Warners.

lands and steep topography. We strongly urge the City of Kentwood Parks and Recreation Department to continue caring for this site in order to maintain the integrity of such a noteworthy example of southern Michigan floodplain habitat.

In sharp contrast, the Crystal Springs Plaster Creek site was the most degraded of the seven parcels. Of necessity, our inventory included only the portion of Plaster Creek floodplain that flows north from the Leisure Creek Drive bridge, within the condominium complex. Initially we intended to include the creek corridor south of the bridge to 68th St. SE in the study, but we found it to be an extremely narrow and eroded channel with adjacent vegetation consisting mostly of invasive trees and shrubs. That area subsequently became a restoration project of Calvin University's Plaster Creek Stewards initiative in 2021–22 (Figure 10) (Calvin University 2023), funded by the Michigan Department of Environment, Great Lakes, and Energy. This restoration project will also include a major enhancement of the downstream section of floodplain that was included in this present study (Figure 2).

Many urban streams have become dangerously degraded over time due in part to the conversion of floodplain habitat to human-dominated landscapes. Damage done to these native floodplains has in turn hindered the important environmental services that healthy floodplains provide when floodwaters rise. Restoring streams back to healthier, more functional ecosystems will require bringing back floodplain habitats through restoration efforts. In the Plaster Creek watershed, locations such as Stanaback, Ken-O-Sha, and Paris Park still provide important

environmental services. These parks are also important reference ecosystems that help restoration and conservation practitioners understand which species can persist in floodplain ecosystems within developed landscapes, thereby helping to inform successful future restoration efforts. Furthermore, these communities are important sources of native propagules for organizations like Plaster Creek Stewards who are working to increase the presence of functional and biodiverse floodplain habitat through ecological restoration efforts.

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THE MICHIGAN BIG TREE PROGRAM

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ABSTRACT

The Michigan Botanical Society (MBS) hosts and maintains a state register of the largest trees occurring in the State under the Society's Michigan Big Tree Program. Initiated in 1956 by Paul Thompson, who was also its first coordinator, the continued tracking of our big trees has been carried out by MBS botanists through the volunteer efforts of subsequent Big Tree Program coordinators Elwood Ehrle, Andrew Sawyer, and Ted Reuschel, as well as numerous more certifiers over the years and more than 40 current volunteer certifiers. The Big Tree register displays 639 trees as currently active. Field checking of species during 2022 by certifiers yielded 19 new or reconfirmed state champions. Five specimens submitted to the American Forests' National Registry of Big Trees during 2021 are still national champions. Information is presented regarding development of the Society's Big Tree register along with instructions for accessing it online, both by computer and by smart phone.

KEYWORDS: big trees, state and national champion trees, Michigan Botanical Society, Michigan Big Tree Program.

INTRODUCTION

Trees, especially very big trees, have always held a special fascination for people. Not only can they enormously outsize any other living thing, but they also may outlive us by several generations. Recognizing this, it is perhaps only natural that records would begin to be kept and friendly competition arise to see where the very biggest trees reside. Thus most, if not all, states now maintain such a register—finding, measuring and registering the largest individual of each species. Each state has an agency or organization that has stepped up to sponsor the program in their state. In Michigan it has been the Michigan Botanical Society (previously known as the Michigan Botanical Club).

Aside from general public interest, why is it important to maintain such records? As stated on the Society's website for the Michigan Big Tree Program:

> First, it is a vital record of a precious natural resource. These trees are typically the oldest of their type, and therefore their genetic material is also the oldest and may play a critical role in species preservation. These trees are also growing at the physiological limit for their species, and if global climate change is coming these trees will likely be the first to be affected. The register is also important because humans have always enjoyed a close relationship with trees. Many of us had a favorite tree from our childhood, a tree that provided shade, adventure, inspiration, or recreation. Trees have also been central to our history and our faith. Consider the metaphors of the "Tree of Life," "Our Family Tree," or "Our Roots," or the role that council trees and trail marker trees have played in our history. The register stands as a record of grand examples of these historically, spiritually, and personally important trees.

HISTORY

In September 1875, "in response to rapid and wasteful postwar development and intense wildfires," concerned citizens founded the American Forestry Association, later renamed American Forests (American Forests 2023a). Over ensuing decades their conservation pursuits focused on such conservation efforts as promoting the need for a national forest system (U.S. Forest Service), collaborating with President Franklin D. Roosevelt in the establishment of the Civilian Conservation Corps, pioneering tree planting as a social responsibility on a national scale, and providing a platform for legendary conservationists such as Gifford Pinchot, Aldo Leopold, and Ansel Adams. As a natural outgrowth of its efforts to advocate for wise management and conservation of forests for future generations, American Forests established the National Champion Trees Program in 1940 to engage the public in forestry activities by way of a national search to discover and document the largest living tree of each species in the United States.

American Forests has published its National Registry of Big Trees ever since with the initial support of the Davey Tree Expert Company and, on an ongoing basis, in collaboration with state coordinators. These standings were eventually published every two years, and the Official Register of Champion Trees is now posted on the Internet (American Forests 2023c).

Michigan was among the first states to follow the lead of American Forests and began searching for its own state (and possibly national) champions. The Michigan Botanical Society (MBS) was organized in 1941 (albeit under a different name than it currently has) and initiated its own Big Tree Program soon afterward. Paul Thompson, a research associate at the Cranbrook Institute of Science in Bloomfield Hills, Michigan, became MBS's first Michigan Big Tree Program Coordinator and began the accumulation of an official record of the state's largest trees of each species. Early records were of course maintained manually and printed by typewriter. Paul Thompson also published status accounts of Michigan's big trees in *The Michigan Botanist* that were especially focused on champion trees, including 17 national champion trees (Thompson 1975, 1986), as well as a popular article that appeared in the magazine of the Michigan DNR (Thompson 1983).

Paul Thompson served as Michigan's State Coordinator for over 40 years until his death in 1994 (Fitzstephens et al. 1994). At that time the position was transferred to Dr. Elwood B. ("Woody") Ehrle, a botanist who was then the President of the Michigan Botanical Club and who had served as Professor of Biological Sciences and Provost at Western Michigan University (WMU) (WMU News 2009). Program efforts and records were centered there for 15 years, during which Ehrle published numerous papers on Michigan's champion trees and shrubs in *The Michigan Botanist* (e.g., Ehrle 1997, 2003, 2006; Ehrle and Thompson 1992).

During the early decades of the program, the list of trees on the Michigan Big Trees register grew dramatically, at one point reaching over 1100 active specimens. Contributing to this growth were the concerted efforts being made by sev-

FIGURE 1. Register # 1305. Black walnut, *Juglans nigra*, Kalamazoo County. With Deb Hoeksema. Photo by Roger Hoeksema.

eral tree specialists with access to a great variety of species in a concentrated setting. Notable among them were:

Jeff Boddy of the Leila Arboretum in Battle Creek. The Arboretum dates to 1922 when the land was donated to the city of Battle Creek. Soon afterwards, a number of trees were planted that make up some of the largest specimens today. It was then largely idle until 1981, when a group of citizens established the Leila Arboretum Society. There are now more than 2,500 marked trees and plants. (Brett Myers, pers. comm.) Thanks to Jeff Boddy, a number of them are now on the state register of big trees.

Stuart Bassett of the W. K. Kellogg Biological Station. The station was once the summer residence of cereal magnate W. K. Kellogg. Beginning in the late 1920s, he not only cared for the surrounding natural forest, but also planted a wide variety of other trees and species. Upon his death, the lands and properties were gifted to Michigan State University. As groundskeeper, Stuart Bassett began caring for the trees in 1980 and set out to conduct an inventory of the

FIGURE 2. Register # 1256. Bur oak, *Quercus macrocarpa*, Berrien County. With Greg Carra. Photo by Don Carra.

species growing there. In 1983, having seen an article in the local media about a "Big Tree Contest" and noting that even the planted specimens were over 50 years old and of considerable size, he entered a number of them in the contest. Several turned out to be state champions. Contest entries continued to be made in ensuing years and also made their way into the Michigan Big Tree Register. Mr. Bassett retired in 2022. (Stuart Bassett, pers. comm.)

Robert Bloye. During the late 1980s, Robert Bloye enrolled at the University of Michigan to pursue graduate work in Forestry. There several professors, including Burton V. Barnes and Warren H. Wagner, Jr., who had collaborated on publishing *Michigan Trees* (Barnes & Wagner 1981; revised edition 2004), the preeminent guide to the trees of the Great Lakes region, persuaded him to join the Huron Valley Chapter of the Michigan Botanical Club (now MBS). That connection led to meeting big tree enthusiast and Michigan Big Tree Coordinator Paul Thompson, whom he subsequently accompanied on a number of big tree searches. Bloye later accompanied Woody Ehrle, then the Michigan Big Tree Coordinator, on many additional big tree jaunts. During the 1990s he and Woody developed a primitive register to document their discoveries. While at the University of Michigan, Bloye measured and recorded most of the trees on campus and in the University of Michigan Arboretum. He later enrolled at Michigan State University (MSU) in 1996 to pursue additional work in Forestry, specializing in dendrochronology. While teaching on the MSU campus and preparing for an overseas trip, he received a vaccine injection which left him quite ill and ma-

FIGURE 3. Register # 2286. Trembling aspen, *Populus tremuloides*. Chippewa County. With Casey Cloeter. Photo by Casey Cloeter.

rooned on campus. To make the best of it, he undertook to measure most of the trees and shrubs on campus. (Robert Bloye, pers. comm.). In time some of them found their way onto the state register of big trees.

Woody Ehrle continued to oversee the program from WMU, including the beginning of a computerized listing of specimens. Also, beginning in 1992, he was the first author of many papers in a new series about Michigan's champion trees published in *The Michigan Botanist* (Rabeler 1992). Initially with Paul Thompson and later with other authors, Ehrle published many short, individual accounts of each species. He also authored the most recent in-depth articles about the Michigan Big Tree Program, listing all of the champion trees and shrubs on record for the State (Ehrle 1997, 2003, 2006). In addition to a more elaborate

FIGURE 4. Register # 1958. Black ash, *Fraxinus nigra*. Gogebic County. With Joseph Youngman. Photo by Justin Miller.

history of the early program years, an overview of the techniques for measuring big trees was included, and a hope that interested individuals would continue to correct, update, and expand the big tree listings. Ehrle's (2003) article included a complete listing of all of the individual trees for which reliable data was available at that time. During the period between 1992 to 2005, numerous articles by various authors, many of them by Ehrle, appeared in the pages of *The Michigan Botanist* focused on individual discussions of 49 species of trees common to Michigan.

Upon the death of Dr. Ehrle in 2008, he was succeeded as Michigan Big Tree Coordinator by Andrew ("Andy") Sawyer. A member of the Southwestern Chapter of the MBS who also served as the organization's webmaster, Sawyer devel-

FIGURE 5. Register # 2259. Ironwood, *Ostrya virginiana*. Washtenaw County. With Tim Eiseman. Photo by Irene Eiseman.

FIGURE 6. Register # 1208. Red pine, *Pinus resinosa*. Gogebic County. With Justin Miller. Photo by Justin Miller.

oped an updated digital register and used the improved version that he and Ehrle developed to track the ever-growing and ever-changing list of entries. Its 2012 version was titled the "Michigan Big Tree Register Species List." Not long afterward, however, the computer program became inoperative and could not be restored. This was a serious problem, and a variety of options for outside assistance were considered. With no likelihood of success in restoration in sight, in 2018 the new webmaster of the MBS, Sheila Bourgoin, was able to capture an earlier record of some 800 trees and transform it into a new computer program and register, which remains in use today (Michigan Botanical Society 2023a).

When Andy Sawyer retired from his position as State Coordinator late in 2017, he was succeeded in January of 2018 by Ted Reuschel, a retired forester from the Michigan Department of Natural Resources. About 150 new trees had accumulated which had been manually maintained by Mr. Reuschel during the period while the MBS Michigan Big Tree computer program was inoperative; and they were then added to the new register.

Ted Reuschel then began a review of the various records of big trees to assure that all past records were accounted for in the new MBS register and were also up-to-date. The new register, constructed from available data in 2018, was compared with that recorded in the prior MBS program. Additionally, MBS member Jim Charvat was able to obtain a printed copy of the 1999 record kept at WMU. This was also compared. In both cases, discrepancies and missing trees were evaluated, and to the extent reasonable, brought into agreement, updated, or dismissed from consideration for various reasons.

As suggested by the early titles of the various listings, which included the terms "inventory" and "shrubs," these lists grew to include a very large number of trees and shrubs. The result was a record of some 1500 specimens! It was found that these records included a vast number of species, including non-natives (often cultivated in private yards or public places), hybrids and varieties, and small shrubs, many of which were very difficult to identify by anyone but an expert botanist. Frequently, there was only one representative of a species on the entire register, which was thereby automatically considered a champion. The records also included many species that would never reach typical tree size or form. Furthermore, per national and state standards, each of these would also require a 10-year re-measurement in order to remain active. During this same time, field re-visits and data updates for previously registered trees had been relatively limited, so that a large inventory of outdated information was accumulating.

This presented a big task for the State Coordinator and the field certifiers. Consequently, the MBS Michigan Big Tree Committee agreed to pare down the list of species that Michigan would track, including elimination of most species in the "shrubs" category. This was completed in 2019 and endorsed by the MBS Board of Directors. Over time, therefore, the focus of the program has shifted from a broad and open scientific inventory of large specimens to a publicly appealing register limited to Michigan's bigger trees.

TABLE 1. Michigan Big Tree Program volunteer certifiers active between 2017 and 2022. SLP = Southern Lower Peninsula, NLP= Northern Lower Peninsula, EUP = Eastern Upper Peninsula, WUP = Western Upper Peninsula.

Banda, Nik, SLP	Gordon, Meghan, SLP	Reuschel, Ted, SLP
Becker, Nia, NLP	Graeff, Alex, WUP	Reuschel, Tedd, SLP
Bielecki, Jim, NLP	Grieshop, Winona, WUP	Sailor, Byron, WUP
Botti, Bill, SLP	Grieve, Jerry, NLP	Sillings, Darrell, SLP
Brandon, Eric, NLP	Hagan, Donna, NLP	Sinnaeve, Kelly, NLP
Brondyke, Bill, WUP	Hallfrisch, Patrick, EUP	Skean, Dan, SLP
Brooks, Matt, WUP	Hansen, Bill, SLP	Smith, Kelley, SLP
Buchanan, Zach, EUP	Hoeksema, Rog and Deb, NLP	Solomon, Zachary Hough, NLP
Burhop, Carl, SLP	Hunter, Ben, WUP	Spiedel, John, SLP
Carra, Don, SLP	Kaiser, Joe and Jodi, EUP	Stemple, Matt, SLP
Caveney, Ned, NLP	Koops, Lance, SLP	Theiner, Bob, NLP
Collins, Anne, EUP	Koski, Marie and Mark, SLP	Thiel, Susan, NLP
Darling, Jason, SLP	Kraft, Adam, SLP	True, Marion, WUP
Denning, Rod, SLP	Lindberg, Linda, WUP	Veneberg, Brad, EUP
DeVet, Carly, WUP	Lucas, Rick A., NLP	Wallace, Alicia, SLP
Dickinson, Hunter, NLP	Miller, Justin, et al, WUP	Wendling, Dave, SLP
Edwards, Bob, WUP	Mohlman, Jerry, WUP	Willis, Gary, WUP
Eiseman, Irene and Tim, SLP	Mueller, Lee, SLP	Woodrich, John and Andy, SLP
Gatesy, Greg, and DeBoer, Cal, SLP	Parker, Dylan, EUP	Young, Joe, SLP
	Pilon, Jack, NLP	

BIG TREE CERTIFIERS

A program of this magnitude would be impossible to carry out without a team of enthusiastic and dedicated volunteer certifiers around the state who conduct inspections in the field. There are currently more than 40 volunteer certifiers working statewide to keep the Michigan Register up-to-date and to assure that new trees are carefully reviewed in a timely manner. During each year a few certifiers retire, but others are gained. Additional certifiers are needed in some areas. Table 1 lists certifiers active in the program since 2017.

Anyone can become recognized as an MBS Big Tree certifier. All it takes is (i) a willingness to travel around a county or two, (ii) an ability to confirm the identity of tree species or to identify the species using a key, and (iii) an ability to take and record accurate measurements using a measuring tape, a forestry tape, or a smart phone with a height and diameter app and GPS capability). Certifiers take photos of the trees they are evaluating, which are also needed for documentation. Each certifier is provided with Michigan Botanical Society/Big Tree Program business cards that help to establish legitimacy when they knock at the door of folks with potential big trees. The card, which has the certifier's phone number and email address, can be left with a short note on the back when an owner is not home. Certifiers can also purchase safety green T-shirts or sweatshirts to provide improved visibility when working in the woods or along busy roadways and help identify bonafide certifiers with the MBS Big Tree program.

GENERAL PROGRAM OBJECTIVES

Each year the Michigan Big Tree program receives new nominations or referrals and measures and certifies new trees in the field. Like the National Register of Champion Trees, which requires re-verification of national champions every 10 years, the Michigan program also updates the measurements for the top ten trees of each species that have not been revisited within the previous ten years. It is also necessary to delete any trees from the register that have died, have been cut down, or have been severely damaged.

Standards and Procedures

The Michigan Big Tree Program, like that in most other states, directly follows the standards and procedures developed by American Forests, and described in its Measuring Guidelines Handbook (American Forests 2023c), instituted in about 2019. Following these procedures builds on and relies upon the experience and expertise of a team of experts at the national level and provides consistency for comparisons among states across the country. Information on how to measure a Big Tree is posted on the MBS website (Michigan Botanical Society 2023b).

INSTRUCTIONS AND PROCEDURES FOR CERTIFICATION

Basic guidelines for Michigan certifiers, which are to be followed in gathering all of the pertinent data on each tree, are summarized in the MBS document *Procedures for Certifiers: Basic Steps*. This is available from the Michigan Big Tree Coordinator upon request. Certification and other special program instructions and procedures are on file in the archives of the MBS in the documents that are listed below. In general, for most trees, the procedures are simple and consistent, and require obtaining a total point score for a candidate tree based on (i) girth in inches, measured at 4.5 feet above the ground, plus (ii) height in feet, plus (iii) one quarter of the average crown spread in feet. There are of course exceptions to the norm in nature that require modifications to these procedures. For example, branching or abnormalities may occasionally occur at the 4.5 foot girth height, or the tallest limb may not be situated over the base of the tree or might extend over a slope or depression or mound, or the crown spread may be highly irregular or may reach partly across a neighbor's fence or a river or pond. Procedures for dealing with these exceptional circumstances are also covered in a number of the documents listed below.

In the interest of insuring the program continues into the future and that its details are carried out consistently and accurately, several documents have been prepared that detail what and how to perform the responsibilities of the State Coordinator and the field certifiers. These documents are based on the national standards of American Forests and are on file in the MBS archives, or they can be requested from the Coordinator. They are:

Responsibilities and Procedures for the State Coordinator
Procedures for Certifiers: Basic Steps
List of Big Tree Certifiers
Guidelines for Listing of Trees on the Big Tree Register
List of Species Not Tracked on the Michigan Big Tree Register
How To Verify Trees Nominated for National Champion Status: Guide for State Coordinator
Michigan Big Tree Record Form

STATUS OF MICHIGAN BIG TREES IN 2022

The focus, variety, and level of activity undertaken by big tree certifiers in a typical program year are illustrated by the following summary of the 2022 calendar year.

The Michigan Big Tree website includes a nomination form for individuals who believe they may have an exceptionally large specimen (Michigan Botanical Society 2023c). Completed nomination forms are automatically forwarded to the state coordinator for initial evaluation. During 2022, 74 nominations were submitted through the MBS website—a rate of about six per month. An additional 86 nominations did not use the MBS website, and instead came directly to the state coordinator or were reported through certifiers by outside observers. The 160 nominations submitted represented 41 of Michigan's 83 counties. Of these new nominations, 31 trees were determined to be too small to warrant an on-site inspection by volunteer certifiers. Another 10 were disqualified without visit due to obvious multi-stem origin. Two were of a species not tracked in Michigan, and three were trees already on the register. Of the remaining 114 nominations, 97 trees were visited, and 17 trees remained to be checked at the end of the calendar year.

During 2022, certifiers also continued to evaluate the status of the roughly 260 trees which had been found listed on an older unpublished register, titled *Michigan Big Tree and Shrub Inventory—1999*. This register had been maintained by Woody Ehrle while he served as Coordinator, and some of its entries dated back to 1958. From this list one more tree was able to be evaluated in 2022, leaving just six trees remaining to be checked in subsequent years.

In accordance with national and state standards, certifiers also performed the 10-year updates for trees already on the Michigan Big Tree Register. They were able to complete 24 re-visits of these, either through field inspection or other determination. About 13 trees still remained to be re-inspected at year's end.

The National Registry of Champion Trees, sponsored by American Forests (American Forests 2023b), has its own set of national champion nominations, submitted directly to it by individuals, bypassing the state big tree programs, although its register does list all state big tree programs and their coordinator contact information. There were around 72 of these that came to the program's attention in 2021. A systematic review of these at that time had found that 23 were already smaller than the current national champion and therefore not contenders

and not warranting further attention. Some 39 others were found to be multi-stem, dead or lost, or of a species not tracked by Michigan. For the 10 or so that still had potential, those field inspections were all completed by the end of 2021.

The net result of all of these efforts was that the 2022 program ended with 639 trees listed as active on the register. Of these, our certifiers had measured 19 trees which either became brand new state champions or were confirmed as continuing state champions after their 10-year re-inspections.

2021 NATIONAL CHAMPION TREES

American Forests maintains the register of the largest trees of each species in the nation. At one time, several decades ago, Michigan had 53 national champions on the register. Over time, other states stepped up their searches and found larger trees. Also over time, since national champions require 10-year updates, some of those in Michigan fell off the list for lack of attention. Only one remained a national champion. However, during 2021, eight new specimens were submitted to the National Registry of Big Trees for national champion consideration. Five of them were declared new national champions. A sixth, a red pine, is pending further review. They are listed in Table 2, with photos on the preceding pages.

It should be noted that in 2022 the American Forests organization determined that it was no longer able to oversee the national champion tree program and was seeking a new sponsor.

ACCESSING THE BIG TREE REGISTER

The data resulting from field activities of certifiers is entered by the state co-

TABLE 2. Michigan's official national champion trees as of 2021 (beginning in 2022, American Forests temporarily suspended its national big tree program).

Big Tree ID number	Common Name (*Latin name*)	County	Score	Girth (inches)	Height (feet)	Crown Spread (feet)
1305	Black walnut (*Juglans nigra*)	Kalamazoo	376	242.2	102.4	124.8
1256	Bur oak (*Quercus macrocarpa*)	Berrien	448	325	91.3	127
2286	Trembling aspen (*Populus tremuloides*)	Chippewa	247	117.5	119	42
1958	Black ash (*Fraxinus nigra*)	Gogebic	274	142.6	114.7	66.5
2259	Ironwood (*Ostrya virginiana*)	Washtenaw	199	112.3	70.3	67
1208	Red pine (pending) (*Pinus resinosa*)	Gogebic	248	119	118.6	41

ordinator into the register of trees that is viewable on the MBS website. Readers who wish to access the MBS Big Tree register to search for information about a particular species or individual Big Trees may refer to Appendix 1 for detailed instructions for doing so.

SPECIAL CONSIDERATIONS AND FREQUENTLY ASKED QUESTIONS (FAQS)

The Michigan Botanical Society recognizes that there are other interests by big tree enthusiasts and that many people have reasons to be fascinated by big trees other than their huge size alone. It should be noted that there are Facebook pages and other websites that are potentially filling the void between scoring big tree size and just enjoying other features of big trees. Such sites are welcome, and independent specialty programs are preferable to making sweeping compromises to modifying the current MBS Michigan Big Trees program in order to accommodate all potential interests.

Occasionally there are other questions and suggestions regarding the MBS Big Tree Program's philosophies, policies, and procedures. Appendix 2 addresses a number of these frequently asked questions (FAQs). If needed, the MBS Big Tree Program coordinator can be contacted for additional information.

ACKNOWLEDGMENTS

This project could not have been carried out without all the wonderful volunteer Michigan Big Tree certifiers over the many years of the program, and special thanks is extended to all those mentioned in Table 1. Appreciation is expressed to members of the MBS Michigan Big Tree Committee, Sheila Bourgoin, Garrett Crow, and Dan Skean, for their service and input. The MBS is especially grateful to Sheila Bourgoin not only for serving as the Society's webmaster, but also for all the hard work she does to maintain and improve the Michigan Big Tree Register.

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APPENDIX 1. ACCESSING THE MICHIGAN BIG TREE REGISTER.

Accessing the Register from a Home Computer

To view the current register of all active big tree records:

From the MBS website (http://michiganbotanicalsociety.org), click on *Michigan Big Tree Program* in the left-hand column,
On the next screen, click on the words *through this page*
On the next screen, click on the words *View the Big Tree Database on Google Docs*

The Big Tree register data will then be displayed. The records will be in numerical order by Big Tree ID number. Any column can be re-ordered alphabetically or numerically by hovering the cursor just to the right of the letter at the top of that column and clicking on the arrow that appears and on the choice of ordering.

To search for a specific tree, including an inactive one, or if more detail about a specific tree is desired than is displayed on the register, or if some column data is partially hidden:

Go to https://c4cmr419.caspio.com/dp/74645000e1389520deb149ddac90
Enter the user name: Guest
Enter the password: Bigtreeguest
Click on "login"
Enter the tree ID number or other parameter and click on "search."

For further information, scroll to the far right, and click on "view details."

As an example, you might remember that a huge black maple (*Acer nigrum*) in Alpine Township, Kent County, had been declared a state champion in the past, but on the current Big Tree register you find it listed as *Acer saccharum*. When accessing further information, you will find the following under Historical Notes: "Previous record in 2008. However, was misidentified as black maple. 2018 inspection by Don Carra and Garrett Crow determined it is a sugar maple [*Acer saccharum*]. Species was corrected, and updated measurements applied. 2008 measurements were 320-."

There may be times when different arrangements of the Big Tree register may be of use or interest to certifiers or the public. When the Big Tree register is accessed, the trees are readily ordered by species or another category by clicking on the heading of a column, as noted above. However, this method cannot produce an ordering of a species by *total point score*, the factor many are looking for as they evaluate new trees. To view a species sorted according to total point score:

Log into the register as described above
Select the species you are searching for

Click on “search”

Note that there may be gaps between some listings due to photo insertions, so be sure to scroll down in order to view all entries. To re-order by total points score, click on the word “Points” at the head of the column. The entries will re-order by total point score, beginning with the largest.

Accessing Sorted Register Data in the field

It is often desirable when scoring a new tree in the field to immediately compare it to those of the same species already on the register. And it’s helpful to be able to tell the owner on-site how their tree compares with other big trees. Fortunately, the Michigan Big Tree Register can be pulled up on a smart phone from just about any field location, although you may not be able to sort that data to group them by species (as can readily be done on a home computer). Here are several options for accessing sorted register data in the field:

Option 1.

Download the Michigan Big Tree register (which is an Excel file) on your home computer.
Edit the spreadsheet in Excel exactly as you want to view it on your phone.
Save the new file as a pdf.
Connect your phone to your computer with a plug-in cable.
Transfer the pdf data to your SD card or other data location.
Find your file location on your smartphone and open the pdf.
It is important to save the dataset in the format and order desired, because it cannot be edited or sorted on the phone, although it will be easy to scroll through.

Option 2.

Proceed as in Option 1 through saving the file as a pdf. Send the pdf file as an attachment to an email sent to yourself.
Open the email on your smart phone and click on the pdf attachment and scroll or enlarge as desired.
Note that you will need to leave the email active on your phone in order to have it remain available.
You can also readily obtain information for saving information to iPhones or Androids by searching on the phrase “transferring pdf files from computer to iPhone or Android” in your browser.

APPENDIX 2. FREQUENTLY ASKED QUESTIONS (FAQS) ABOUT THE MICHIGAN BIG TREE PROGRAM.

FAQ 1. What is the basis for the standards and procedures that the MBS has adopted?

In general, MBS has settled on these standards because:

1. They follow national standards that were developed carefully and applied by a team of national experts over many years. We are respectful and confident of their collective expertise and experience.
2. Most, if not all, of the states follow the national standards. Comparisons across the country would be complicated if there were substantial differences.
3. Several states have suspended or paused their programs for lack of leaders or field certifiers. If the program gets too demanding or complicated, this could be the fate of the program in other states.
4. The primary philosophy of both the national and Michigan Big Tree programs is to find and register only a limited number of the very largest trees of each species rather than all the trees that might be considered big. The national program recognizes only the single biggest specimen of each species. Michigan includes up to about 10.
5. Internal discussions within the MBS leadership, in particular the three-person “Big Tree Committee,” over the years have settled on these standards as the most reasonable.

FAQ 2. Why is the number of registered trees in the database kept to a minimum and not simply left to accumulate thousands of big trees?

1. The overriding objective of the MBS is to list the several very biggest trees of each species for the interest and enjoyment of the general public. The register size becomes more unwieldy, more intimidating, and less user friendly for the average citizen as the number of tree listings increases.
2. Most big tree owners seem to be considerably less impressed by being number 11–25 on the list than by being able to say "top ten." Hence, the decision was made to list as active only the top ten trees of a given species, realizing that more is generally superfluous to the interests of the casual public.
3. Since tree status (i.e., still living vs. dead or diminished) changes over time, national and state standards mandate that each tree on the register be revisited every ten years. This is only fair to the runners-up who would potentially move to a higher position in the ranking. But that of course entails that an average of 10% of the total registry needs to be re-visited and updated each year. Certifiers already are pressed to keep up with these updates with just the current 600 or so trees on the register. In addition to these updates, we receive many new nominations each year that must be considered—in 2022, for example, 160 new nominations were received.
4. In order to have adequate back-ups when some of the top 10 trees die or are cut, it should be noted that MBS does in fact have more than 10 trees recorded for many of the more common and popular species. As the list grows, the state coordinator periodically moves trees scoring lower than the top ten to inactive status. They remain in the register but are not viewable by the public and therefore do not take up a lot of space on the visible register. If necessary, some of those can be reactivated if the number on the active register drops below 10 or so. But in general, the list of new trees is still growing faster than registered trees are dying.
5. As noted above, it is still a struggle to visit every tree that is newly nominated; it requires a lot of time and travel. So in the interest of not stressing the volunteer certifiers, new nominees of species that are already well-represented by apparently larger-sized individuals are not even referred for field inspection.
6. There is an ongoing search for more certifiers to ease some of the program's time restraints, and a few areas of the state could still use additional volunteers. In general, a couple are gained, and a couple are lost each year.
7. County-level competition has not been promoted simply because there would then be pressure to list 10 trees *per county*, thereby greatly increasing the size of the register.
8. At some point, the size of the database becomes larger than permitted by the google-docs program that we utilize. Photos that generally accompany each big tree entry particularly impact the database size, and are therefore reduced in size to less than one megabyte each.

FAQ 3. Why are only certain species tracked on the Michigan Register and others excluded?

1. This keeps the register size manageable, maintains maximum interest by casual citizens, and enables certifiers not necessarily experts in botany or dendrology to identify most species on the list. With this in mind, the MBS has determined that it will continue to list:

    a. All species native to Michigan that typically reach tree form and size, including those commonly considered understory species, such as *Hamamelis virginiana* (witch-hazel).
    b. Those non-native species that are popular and commonly planted in Michigan, are rather easily identifiable, do well, and typically grow to relatively large size
    c. All individual trees of a tracked species in the register that fall within the top ten in points for their species.

2. NOT included on the register are the following, unless their situation is outweighed by the criteria in 1) above:
    a. Most woody species that do not typically reach tree form and size
    b. Most woody species not native to the United States.
    c. Most horticulturally developed cultivars, ornamentals, and varieties of woody plants, and most natural varieties of woody plants.
    d. Most domesticated fruit and ornamental species.

e. Species with only one or two representative specimens for their species (due to their likely appearance only in arboretums, nurseries, university botanical gardens, or the like).
f. Trees that have been on the register but no longer fall within the top 10 in points for their species, and new nominations which would not fall within the top 10.

FAQ 4. Why are some species, even though not fitting the criteria for non-inclusion not represented by any entries in the register?

Individuals of eligible species with no representative may simply not yet have been nominated.

FAQ 5. Why are trees of multiple stem origin excluded from the register?

A 2019 nationally-instituted rule disqualifies trees of multi-stem origin. Michigan has accepted the conclusion of the National Register to make this distinction. In fairness to nominators and owners, girth measurements need to be on a comparable basis. Obviously, if two seedlings came up a few feet apart as distinctly two separate trees and over time pushed together and essentially fused, there would be no question that we were really measuring *two* expanding trees rather than one. This would be unfair to a tree which came up singly! Similarly, if two sprouts came up from the same stump, or one sprout immediately branched at ground level, and then both grew and fused as they continued to press together, we would again really be measuring *two* sprouts or *two* branches rather than one trunk. Again, this would be unfair to compare to a single trunk or branch. Admittedly, this can be a very difficult distinction to make.

FAQ 6. What criteria aid in distinguishing trees of multi-stem origin from those of single-stem origin?

1. On every field inspection the number of originating stems is always the first and often most difficult determination to be made. On both state and national registers, multi-stem specimens are not eligible. Following are some distinguishing details:
2. Technically, if a tree is of single stem origin, cutting it off at ground level would reveal just a single central pith (tree center). A tree of multi-stem origin would reveal more than one central pith. Therefore, by observation a certifier should determine the probable pith lines of each stem or branch between 4.5 feet and the ground. Every stem or branch whose individual pith line seems to extend all the way down to ground level must be considered a separate tree.
   a. However, if the pith line of any stem or branch appears to join the main stem above ground level, it should be assumed that the main stem originated first, and the others were branches developing later and higher, on and from the main stem. This is then properly considered of single-tree origin, and classified as a qualifying single tree.
3. While the supposed pith line is the key factor in classification, it is not always definitive enough. In such cases, other factors may aid in determination.
4. Perhaps the simplest indicator is when the two stems have not yet progressed very far in their merger, and an oval or figure eight cross section is still evident. Trunk outline and intact bark still curve inward where they meet. A single stem will be more likely to have a nearly round cross section.
5. It is more difficult when the merger has progressed farther. There is often a vertical crease or fissure where the two stems have eventually pressed together. Sometimes it is flush with the rest of the trunk. Other times it may still be slightly incurved, and still other times the pressure from growth is so great that the crease bulges outward. A caution here, however: lightning strikes may create similar features.
6. Study the entire circumference to look for complimentary indications on opposite sides. With merged stems, a crease or irregularity on one side of the tree will often (but not always) be evident on the other side. When it is not present on the other side, the determination leans somewhat more closely to a single stem possibility.
7. Since a typical tree tapers from its greatest girth at ground level on up to its very top, another approach which can aid in the determination is to note that trees of multiple stem origin usually have their greatest girth *higher* than ground level. This is because those multiple stems or branches are immediately growing outward and reaching out and away from each other. Thus, even though the individual trunks may no longer be distinct, their presence is rather obvious by an *increasing* girth as one moves up the trunk from ground level.

8. Looking up to the point where the trunk first clearly separates into two stems or branches can often be helpful. The angle at which one meets the other can be a clue. With a merger of two individual stems, they are close to parallel, especially the closer they get to ground level. But when the second stem meets the first more abruptly, as is exaggerated in the form of the Joshua Tree cactus, its origin is more likely a single stem. The second stem is then more likely to be a very low branch which formed slightly later. Alignment of bark strips can aid in tracking these branch angles.

FAQ 7. Does MBS furnish plaques for the highest-scoring trees of each species?

Although this was done for a time in the past, the practice has been discontinued. Part of the reason is the associated costs and practicality of producing and distributing the plaques. A further significant factor, however, is that with more than 100 new nominations submitted annually, the ranking of trees is continuously changing. It would also be disappointing to owners to have their plaque removed when larger specimens are found. However, a paper certificate can be provided upon special request to the state coordinator.

FAQ 8. Where are big trees most likely to be found?

1. Contrary to what might be expected, the biggest trees are probably least likely to be found deep within a forest. In such locations, competition for sunlight, water and nutrients is too intense, and inhibit growth.
2. Instead, by far most of the trees on the register are found in residential yards, along city streets and rural roadsides, in parks and cemeteries, in university plantings and arboretums, and in fencerows, farmlands, and open fields.

FAQ 9. Why are locations of big trees made public on the register? Doesn't this make them vulnerable to vandalism, trespass, litter, wear, or other damage?

1. Most private owners by far are happy and proud to have their tree on the register. Of course their trees are usually well protected simply by being on private property and often right in their yard. In a few cases, owners have expressed concern with listing of the tree's location, and their concern has been honored by withholding location data.
2. On public property, trees may be more vulnerable. But it's hard to imagine a Big Tree program that does not provide the opportunity for enthusiasts who want to see them. It seems that not many people actually go searching. And most such observers are, by their nature, respectful and protective of such specimens. It is believed that vandalism would be an extremely rare case, and no such cases have been reported in Michigan. There is of course a very small risk, but the program would potentially suffer by providing only a stoic list of inapproachable trees. Searching out monster trees is very exciting and rewarding for some.

FAQ 10. Is there a map showing the location and distribution of all registered trees?

Yes. A map showing the location of Big Trees in Michigan is available at https://www.google.com/maps/d/u/1/edit?mid=10bhoqyhFQyeU8mwj3hLL3pe15qCMuiC5&usp=sharing. Clicking on the tag at each location will bring up data for the tree at that location.

FAQ 11. Can big tree owners have their trees re-measured in advance of the scheduled 10-year update?

Generally not. Typically, MBS doesn't do updates prior to the 10-year update unless the tree in question is reported to be either dead or diminished. It has been found that some owners like more frequent updates for their own personal reasons or simply because they think they can get a jump on the current state champion by scheduling an earlier update. MBS tries to avoid having certifiers pulled back and forth on such issues when they already have more than enough to do. Hence, for consistency MBS prefers to stick to the rigid 10-year schedule

FAQ 12. Who may be contacted for additional information?

Contact the state coordinator, Ted M. Reuschel, tbreusch@comcast.net.

ECOLOGICAL AND FLORISTIC PLANT SURVEYS OF LITTLE WABASH RIVER NATURE PRESERVE, INDIANA

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ABSTRACT

Forests in northeastern Indiana are relegated to relatively small fragments and have become important patches in a landscape dominated by agriculture. Little Wabash River Nature Preserve is a property in Allen County, Indiana, closed to the public and protected by ACRES Land Trust. We conducted ecological surveys at 48 regular plots located along seven transects through the property that consisted of identifying and counting individual plants at understory, midstory, and overstory strata and recording several ecological factors. These were augmented by floristic meandering surveys during the growing season of 2019 to record plant species that may not have been encountered at the ecological plots and thereby give a fuller picture of the floristic composition of the property. We encountered a total of 251 identified species during the ecological and floristic surveys. Analysis showed understory abundance, richness, and diversity were positively related to available light (photosynthetically active radiation) and negatively related to canopy cover. The most abundant species in the midstory were non-native species. *Juglans nigra* had the greatest frequency and dominance in the overstory. In nonmetric multidimensional scaling, there was clear separation of the plant community within the forested portion from the community in the adjacent to the small old-field. Mean C-value for the site was 2.87, which resulted in a 41.56 FQI. The FQI may be an over-estimation of the conservation importance of the site and the Mean C-value may be an under-estimation of that importance. Overall, the Nature Preserve provides an example of the plant diversity can exist in a small, protected forest. While there are some common non-native species, there is habitat for a relatively large pool of species and may be of importance for protection within the surrounding disturbed landscape.

KEYWORDS: diversity, fragmentation, richness, nature preserve

INTRODUCTION

Most forests in northeastern Indiana are relatively small and isolated fragments of a formerly contiguous forest (Harman et al. 2019). Where forests do exist, they are often surrounded by artificial habitats, such as agricultural land or urban development. Edge effects on environmental gradients (e.g., light, moisture, temperature) and the limited size of core forest habitat results in changes in plant community structure and composition (Harman et al. 2019; Harper et al. 2005). These forest fragments provide essential landscape heterogeneity that provides habitat for arthropods, birds, and small mammals (Freemark and Merriam 1986; Myers and Marshall 2021; Nupp and Swihart 2000; Proesmans et al. 2019). The preservation of such isolated forest parcels has the potential to im-

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prove animal habitat and to protect rare plant communities (Rosenblatt et al. 1999; Fauth 2000; Diamond and Heinen 2016).

Floristic quality assessments (FQA) provide a systematic, repeatable approach to compare botanical communities within and between sites (Swink and Wilhelm 1994, Rothrock and Homoya 2005). Within FQA, there is a reliance on assigned C-values for each species encountered that facilitates the calculation of a floristic quality index (FQI) as an information statistic. While Swink and Wilhelm (1994) provided assigned C-values for species within the Chicago region, these values likely do not apply to locations outside of that region. For Indiana, C-values were subsequently assigned as only seven counties in Indiana are included in the Chicago region (Rothrock 2004, Rothrock and Homoya 2005). There are several criticisms of FQA, C-values, and FQI (Spyreas 2019), one of which is the subjectivity of assigned C-values. However, as an information statistic, there is aggregation of values within the calculation of Mean C-values and FQI, which will mitigate biases in certain species (Spyreas 2019). Additionally, there is inherent noise in the data related to differences in C-value lists and missing species from surveys (Rothrock and Homoya 2005). There are limitations to FQA and associated Mean C-value and FQI calculations, however, it is currently a usable tool for understanding community structure in relation to anthropogenic disturbance (Spyreas 2019, Werners et al. 2021).

Little Wabash River Nature Preserve (LWRNP) is a 14.3 ha property (of which approximately 13.0 ha is forested) within the Little River watershed that is located in Allen County in northeastern Indiana and is surrounded by agriculture, suburban development, and other forest fragments (Figure 1). LWRNP is situated in a geological valley feature created by the draining of Lake Maumee during the Wisconsin glaciation, known as the Maumee Megaflood (Fleming et al. 2018). Currently closed to the public, LWRNP is managed by ACRES Land Trust, which acquired the property in two units—the largest unit in 2004 (9.8 ha, all forested) and the smallest in 2015 (4.5 ha, 1.3 ha of which is an old field). In addition to ACRES Land Trust, LC Nature Park and Little River Wetlands Project are working to protect land within the Little River watershed. The objectives of this study were to characterize the plant community structure and composition at Little Wabash River Nature Preserve using systematic ecological surveys to associate community structure with environmental conditions and meandering floristic surveys to develop a comprehensive species list. Results from ecological and floristic surveys will be useful to ACRES Land Trust in making management decisions at the property and acquisition decisions in the region.

MATERIALS AND METHODS

Site Description

The property is mostly forested, but a 1.3 ha open field area does exist on the western side (Figure 1). LWRNP is dominated (72% of the area) by Glynwood clay loam soil (6–12% slope, moderately well drained). The southeastern portion of the property (24% of the area) is Eel silt loam soil (0–2% slope, frequently flooded). A small portion (4% of area) of LWRNP is Glynwood silt loam soil (2–6% slope, moderately well drained). Within the forested area, there is a 0.6 ha pond with open water.

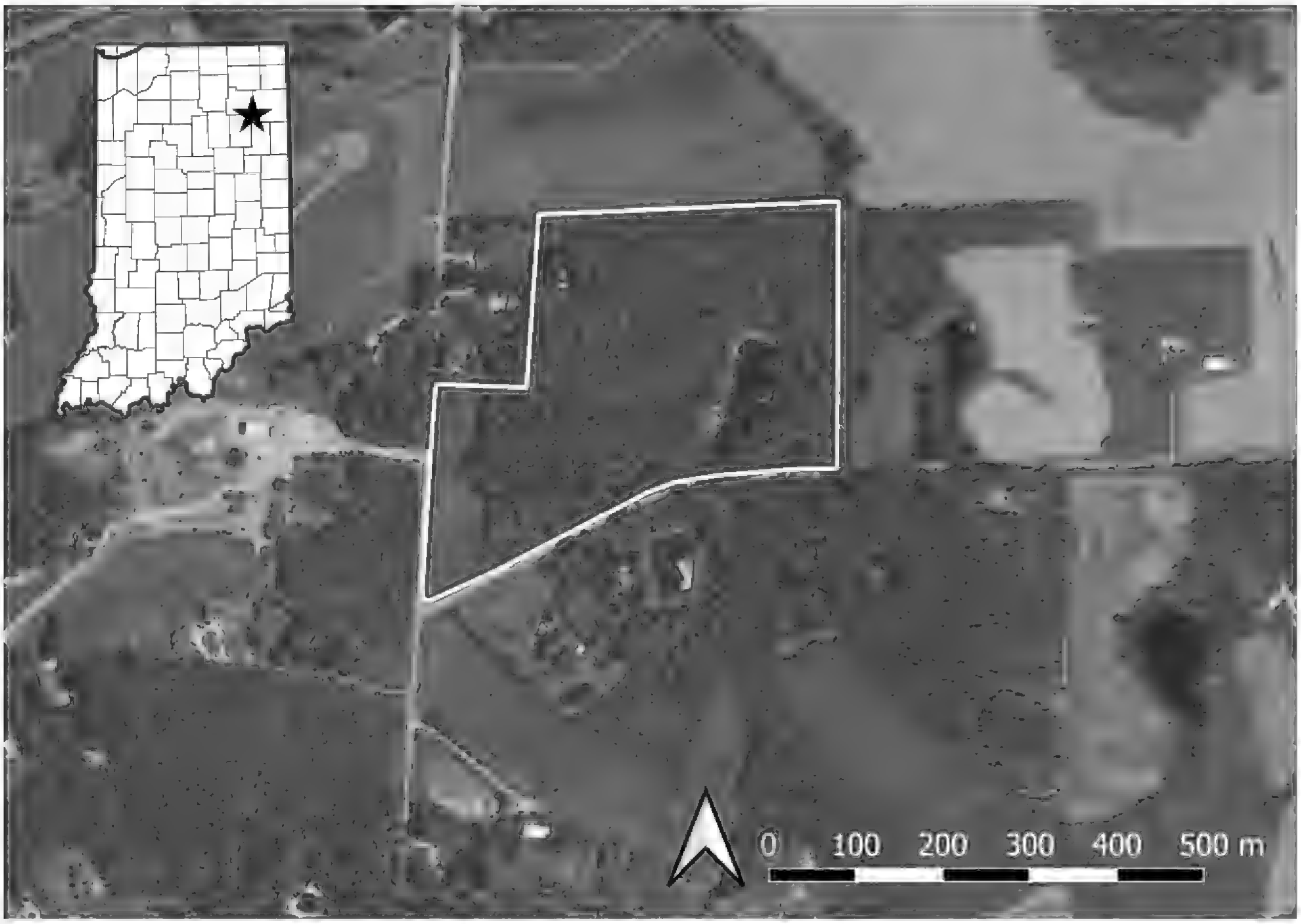

FIGURE 1. Little Wabash River Nature Preserve location and aerial image. Property boundary outlined in white. Aerial image is from the National Agricultural Imagery Program (USDA Farm Service Agency Aerial Photography Field Office).

Ecological Surveys

Understory Surveys and Environmental Conditions

Understory plants were surveyed and ecological data recorded during three seasonal periods: May 13–18, July 13–21, and September 20–21 2019. To link plant community data to environmental conditions, we established seven transects, spaced 50 m apart, running southeast to northwest within LWRNP. Along each transect we established 1 m^2 quadrats spaced 30 m apart; there were a total of 48 quadrats. As the transects were not of equal length, the number of quadrats per transect were not equal. We surveyed all quadrats during the May, July, and September surveys. Within each 1 m^2 quadrat, we identified to species and counted individuals of all plants ≤ 2 m in height rooted in the quadrat. Species nomenclature throughout all surveys follows the Integrated Taxonomic Information System (ITIS, 2023). Voucher specimens were collected when species were encountered for the first time, whenever possible (i.e., we considered the population to be large enough and the species common enough), and deposited in the Purdue University Fort Wayne Department of Biological Sciences herbarium.

At the center of each quadrat, we measured photosynthetically active radiation (PAR) (μmol/m^2/sec) 1 m above the soil surface with a six-sensor linear ceptometer (Spectrum Technologies, Aurora, Illinois), the percentage of volumetric soil moisture content with a time domain reflectometer with 12 cm sensor rods (Spectrum Technologies, Aurora, Illinois), litter depth (cm) with a meterstick, and the percentage of canopy cover with a spherical concave densiometer (Forestry Suppliers, Jackson, MS) using standard protocols (Lemon 1956). PAR light data was converted to percentage of available PAR by dividing the quadrat data by an unattended light sensor continuously logging 100% solar radiation in an open, unshaded portion of the property.

Midstory and Overstory Survey

Midstory plant surveys were conducted on August 10–11, 2019 within 25 m^2 (5 m × 5 m) plots centered on each understory quadrat. All plants > 2 m in height and < 8 cm diameter at breast height

(DBH, 1.37 m above the soil surface) were identified to species and stems were counted for each species.

Overstory plant surveys were conducted on August 10–11, 2019 within 500 m^2 circular plots (12.62 m radius) centered on each understory quadrat. All trees (≥ 8 cm in DBH) were identified to species and basal area (m^2/ha) was determined from 10-factor prism counts for each species. While not identified to species, we also counted standing dead trees. The relative dominance of each species was calculated as the basal area of the species, divided by the sum of the basal areas of all species multiplied by 100. The relative frequency of each species was calculated as the frequency of the species (the number of plots in which the species occurs divided by the total number of plots surveyed) divided by the sum of the frequencies of all species multiplied by 100. The relative density of each species was calculated as the number of individuals of the species divided by the total number of individuals of all species multiplied by 100. The importance values of each species were then calculated as the sum of the relative dominance, the relative frequency, and the relative density of that species, divided by three.

Floristic Surveys

The floristic surveys were conducted between April and October 2019 (18 visits, every 1-3 weeks during survey period, some visits in the same week) to ensure that all habitat areas within LWRNP were visited and that plant species not encountered during the ecological surveys would be cataloged. As the survey transects were spaced 50 m apart, there were clearly areas of the property that were not surveyed. The floristic surveys turned up additional species that were not encountered during the ecological surveys. Due to the stochastic nature of the floristic surveys, the location and environmental conditions were not recorded. However, voucher specimens were collected of species encountered for the first time, whenever possible, and deposited in the Purdue University Fort Wayne herbarium.

Analysis

Floristic Quality Assessment

For all species encountered in the ecological and floristic understory surveys, we used the coefficient of conservatism (C or C-value) assigned by Rothrock (2004) for Indiana for subsequent calculations. These C-values range from 0 to 10 with lower values associated with species that can tolerate disturbance and greater C-values associated with species that cannot tolerate disturbance. A floristics quality index (FQI) was calculated for the site based on C-values and provided a relative comparison value of the conservation importance as a remnant habitat. FQI was calculated as

$$\text{FQI} = \text{Mean C-value} \sqrt{N}$$

where Mean C-value was the calculated mean value for all species C-values at LWRNP and N is the total of native species present in the site. We used Method 2 as described by Rothrock (2004) where non-native species have a C-value of zero.

Statistical Analysis

Species richness (the number of species present) was recorded and the species diversity, using Shannon's index, was calculated for each understory quadrat and each midstory and overstory plot based on abundance (count of individuals). Shannon's index is an information statistic used as a measure of entropy within an ecological community and of uncertainty (Hayek and Buzas 1997). We calculated Shannon's index following Hayek and Buzas (1997) as

$$\text{Shannon's index} = -\sum p_i \log p_i$$

where p_i is the proportion of the ith species ($p_i = n_i/N$, where n_i is the abundance of the ith species and N is the total abundance). Total understory abundance (counts of all individuals), richness, and diversity were analyzed using mixed effect linear regression with each of the following environmental factors: percentage of available PAR, percentage of soil moisture, litter depth, and canopy cover as independent fixed factors and with survey month as a random effect. A Wald chi-square test was used to test the confidence in the influence of the fixed effects on the dependent variable. Nonmetric multidimensional scaling (NMDS) ordination was used to visualize understory plant community

composition at LWRNP based on species stem counts using the metaMDS function in the *vegan* package with default options (Oksanen et al. 2022). Bray-Curtis dissimilarity was used as the distance measure within the NMDS ordination. Through the 'autotransform=TRUE' option, the data was transformed using a Wisconsin double standardization with square root function. Joint vectors were displayed to represent influence of environmental variables on the plot locations in species space. Environmental variables were midstory species richness and diversity, overstory species richness and diversity, overstory dead tree basal area, percentage of canopy cover, percentage of soil moisture, percentage of PAR, and litter depth. We used an $R^2 = 0.2$ as an arbitrary threshold, omitting joint vectors from the NMDS plot that were below the threshold. Unweighted average linkage hierarchical clustering was used to identify separation in clusters within the NMDS plot. All analyses were conducted in R version 4.2.2 (R Core Team 2022).

RESULTS

Ecological Surveys

Understory Survey

We encountered 118 understory species in 47 families (Table 1). Three quadrats had zero individuals and they were different locations during the survey period (one in May, two in September). Thirty-eight of the species occurred in only a single quadrat. Forty-one species occurred on only one sampling date, thirty on two dates, and forty-seven occurred on all three sampling dates.

With month as a random effect, understory abundance ($X^2 = 38.18$, $p < 0.001$), richness ($X^2 = 43.63$, $p < 0.001$), and diversity ($X^2 = 14.64$, $p < 0.001$) were positively related to the percentage of available PAR (Figure 2). Similarly, abundance ($X^2 = 14.37$, $p < 0.001$) was positively related to the percentage of soil moisture, however, richness and diversity were not related to soil moisture ($X^2 = 2.68$, $p = 0.102$; $X^2 = 0.05$, $p = 0.821$; respectively; Figure 2). Litter depth did not have a significant influence on abundance ($X^2 = 1.48$, $p = 0.223$), richness ($X^2 = 2.68$, $p = 0.102$), or diversity ($X^2 = 3.26$, $p = 0.071$) (Figure 2). As would be expected, canopy cover had an inverse influence on abundance ($X^2 = 145.16$, $p < 0.001$), richness ($X^2 = 107.13$, $p < 0.001$), and diversity ($X^2 = 27.13$, $p < 0.001$) compared to available PAR (Figure 2).

NMDS ordination was used to visualize the understory plant community at LWRNP (Figure 3). A small cluster of eleven plots were separate from the other plots within the NMDS. These included plots that occurred in the old field on the western side of LWRNP and along the transects adjacent to the old field. The separation of this cluster in the NMDS was positively influenced by soil moisture and available PAR in those plots. Conversely, this cluster was negatively influenced by canopy cover, overstory richness, and overstory diversity (Figure 3).

Midstory Survey

We encountered 23 midstory species in 12 families (Table 2). Nine plots contained no midstory individuals. The non-native *Lonicera maackii* (Ruper.) Herder was by far the most frequently occurring (i.e., occurred in the greatest number of plots) and most abundant (i.e., with the greatest number of individuals per plot) midstory species encountered (Table 2). Other non-native species

TABLE 1. Species encountered during the understory ecological surveys, the number of quadrats in which each occurred, and the mean number of individuals per quadrat (standard error in parentheses).

Family	Scientific name	Plots	Count
Adoxaceae	*Sambucus canadensis* L.	1	3.0
Anacardiaceae	*Toxicodendron radicans* (L.) Kuntze	16	7.3 (2.5)
Apiaceae	*Cryptotaenia canadensis* (L.) DC.	1	9.0
Apiaceae	*Daucus carota* L.	11	32.0 (7.7)
Apiaceae	*Erigenia bulbosa* (Michx.) Nutt.	1	7.0
Apiaceae	*Osmorhiza claytonii* (Michx.) C.B. Clarke	9	7.1 (1.8)
Apiaceae	*Pastinaca sativa* L.	3	3.3 (1.9)
Apiaceae	*Sanicula canadensis L.*	10	25.8 (8.5)
Apocynaceae	*Apocynum cannabinum* L.	5	8.0 (4.3)
Apocynaceae	*Asclepias syriaca* L.	2	2.0 (0.0)
Asparagaceae	*Convallaria majalis* L.	1	330.0
Asparagaceae	*Maianthemum racemosum* (L.) Link	1	1.0
Asparagaceae	*Polygonatum biflorum* (Walter) Elliott	2	2.0 (0.7)
Aspleniaceae	*Asplenium platyneuron* (L.) Britton, Sterns & Poggenb.	1	3.0
Asteraceae	*Ageratina altissima* (L.) R.M. King & H. Rob	7	11.0 (2.6)
Asteraceae	*Ambrosia artemisiifolia* L.	4	3.0 (0.8)
Asteraceae	*Arctium minus* (Hill) Bernh.	2	2.5 (1.1)
Asteraceae	*Cirsium arvense* (L.) Scop.	2	1.0 (0.0)
Asteraceae	*Erigeron annuus* (L.) Pers.	7	13.4 (6.1)
Asteraceae	*Euthamia graminifolia* (L.) Nutt.	1	2.0
Asteraceae	*Leucanthemum vulgare* Lam.	9	2.8 (0.6)
Asteraceae	*Packera glabella* (Poir) C. Jeffrey	1	1.0
Asteraceae	*Solidago altissima* L.	5	9.0 (2.2)
Asteraceae	*Solidago canadensis* L. var. *hargeri* Fernald	8	28.1 (9.3)
Asteraceae	*Solidago* sp. L.	4	17.5 (8.3)
Asteraceae	*Symphyotrichum lanceolatum* (Willd.) G.L. Nesom	9	20.1 (6.4)
Asteraceae	*Symphyotrichum shortii* (Lindl.) G.L. Nesom	1	5.0
Asteraceae	*Taraxacum officinale* F.H. Wigg.	7	3.4 (1.1)
Asteraceae	*Vernonia gigantea* (Walter) Trel.	2	7.0 (4.2)
Balsaminaceae	*Impatiens capensis* Meerb.	7	10.6 (2.8)
Brassiaceae	*Cardamine douglassii* Britton	1	1.0
Brassicaceae	*Alliaria petiolata* (M. Bieb.) Cavara & Grande	13	16.6 (5.3)
Brassicaceae	*Cardamine concatenata* (Michx.) Sw.	2	8.0 (2.8)
Brassicaceae	*Lepidium campestre* (L.) W.T. Aiton	2	9.5 (1.8)
Cannabaceae	*Celtis occidentalis* L.	10	1.8 (0.3)
Caprifoliaceae	*Lonicera maackii* (Rupr.) Herder	21	5.5 (1.2)
Caryophyllaceae	*Cerastium fontanum* Baumg.	1	4.0
Caryophyllaceae	*Stellaria media* (L.) Vill.	1	4.0
Celastraceae	*Euonymus atropurpureus* Jacq.	2	1.5 (0.4)
Cornaceae	*Cornus drummondii* C.A. Mey	3	2.0 (0.5)
Cornaceae	*Cornus racemosa* Lam.	3	2.0 (0.5)
Cyperaceae	*Carex granularis* Muhl. ex Willd.	1	1.0
Cyperaceae	*Carex jamesii* Schwein.	13	7.5 (2.4)
Cyperaceae	*Carex normalis* Mack.	1	2.0
Cyperaceae	*Carex stipata* Muhl. ex Willd.	7	6.7 (2.2)
Cyperaceae	*Carex vulpinoidea* Michx.	1	7.0
Cyperaceae	*Scirpus atrovirens* Willd.	1	1.0
Elaeagnaceae	*Elaeagnus umbellata* Thunb.	8	6.0 (1.6)
Fabaceae	*Cercis canadensis* L.	3	9.3 (4.8)
Fabaceae	*Medicago sativa* L.	1	1.0
Fabaceae	*Trifolium pratense* L.	9	12.7 (3.4)

(*Continued on next page*)

TABLE 1. (*Continued*).

Family	Scientific name	Plots	Count
Fabaceae	*Trifolium repens* L.	5	9.4 (2.3)
Fagaceae	*Quercus alba* L.	1	2.0
Fagaceae	*Quercus bicolor* Willd.	1	4.0
Fagaceae	*Quercus rubra* L.	2	1.0 (0.0)
Geraniaceae	*Geranium maculatum* L.	1	28.0
Grossulariaceae	*Ribes cynosbati* L.	2	1.0 (0.0)
Hydrophyllaceae	*Hydrophyllum appendiculatum* Michx.	1	1.0
Hydrophyllaceae	*Hydrophyllum macrophyllum* Nutt.	1	2.0
Juglandaceae	*Carya cordiformis* (Wangenh.) K. Koch	2	3.0 (0.0)
Juncaceae	*Juncus tenuis* Willd.	4	4.5 (1.3)
Lamiaceae	*Blephilia hirsuta* (Pursh) Benth.	4	3.8 (1.1)
Lamiaceae	*Glechoma hederacea* L.	3	3.0 (0.9)
Lamiaceae	*Prunella vulgaris* L.	3	8.3 (2.6)
Liliaceae	*Erythronium americanum* Ker Gawl.	3	12.7 (2.6)
Limnanthaceae	*Floerkea proserpinacoides* Willd.	6	13.0 (3.4)
Menispermaceae	*Menispermum canadense* L.	1	8.0
Montiaceae	*Claytonia virginica* L.	1	4.0
Oleaceae	*Fraxinus pennsylvanica* Marshall	27	15.9 (5.0)
Oleaceae	*Fraxinus quadrangulata* Michx.	2	12.5 (5.3)
Onagraceae	*Circaea lutetina* L. ssp. *canadensis* (L.) Asch. & Magnus	14	12.2 (3.0)
Oxalidaceae	*Oxalis dillenii* Jacq.	7	5.7 (2.2)
Phrymaceae	*Phryma leptostachya* L.	1	1.0
Pinaceae	*Pinus strobus* L.	1	3.0
Plantaginaceae	*Plantago lanceolata* L.	10	36.9 (8.5)
Plantaginaceae	*Plantago rugelii* Decne.	3	1.7 (0.3)
Poaceae	*Agrostis gigantea* Roth	9	38.8 (6.8)
Poaceae	*Bromus pubescens* Muhl. ex Willd.	1	2.0
Poaceae	*Dactylis glomerata* L.	2	10.0 (0.0)
Poaceae	*Dichanthelium boscii* (Poir.) Gould & C.A. Clark	5	2.4 (0.7)
Poaceae	*Dichanthelium linearifolium* (Scribn. ex Nash) Gould	7	9.3 (1.8)
Poaceae	*Elymus hystrix* L.	1	7.0
Poaceae	*Glyceria striata* (Lam.) Hitchc.	14	30.3 (5.9)
Poaceae	*Phleum pratense* L.	8	107.1 (22.1)
Poaceae	*Poa pratensis* L. ssp. *pratensis*	2	22.5 (0.4)
Poaceae	*Poa sylvestris* A. Gray	3	15.3 (10.1)
Polygonaceae	*Persicaria virginiana* (L.) Gaertn	22	29.3 (5.4)
Ranunculaceae	*Actaea pachypoda* Elliott	1	10.0
Ranunculaceae	*Anemone canadensis* L.	1	4.0
Ranunculaceae	*Ranunculus abortivus* L.	1	2.0
Ranunculaceae	*Ranunculus recurvatus* Poir.	5	2.2 (0.7)
Rosaceae	*Duchesnea indica* (Andrews) Focke var. *indica*	2	6.5 (3.2)
Rosaceae	*Fragaria vesca* L.	5	6.0 (1.9)
Rosaceae	*Fragaria vesca* L. subps. *vesca*	3	1.7 (0.5)
Rosaceae	*Geum canadense* Jacq.	16	7.5 (1.3)
Rosaceae	*Geum* sp. L.	8	11.6 (4.0)
Rosaceae	*Geum vernum* (Raf.) Torr. & A. Gray	13	2.5 (0.3)
Rosaceae	*Prunus serotina* Ehrh.	6	1.5 (0.2)
Rosaceae	*Rosa multiflora* Thunb.	7	5.9 (1.6)
Rosaceae	*Rubus occidentalis* L.	6	5.7 (1.3)
Rubiaceae	*Galium aparine* L.	18	5.4 (0.9)
Rubiaceae	*Galium asprellum* Michx.	1	1.0
Rubiaceae	*Galium circaezans* Michx.	1	1.0
Rubiaceae	*Galium concinnum* Torr. & A. Gray	2	6.5 (3.2)

(*Continued on next page*)

TABLE 1. (*Continued*).

Family	Scientific name	Plots	Count
Rubiaceae	*Galium triflorum* Michx.	7	3.1 (0.8)
Sapindaceae	*Acer saccharum* Marshall	6	2.3 (1.0)
Sapindaceae	*Aesculus glabra* Willd.	1	2.0
Smilaceae	*Smilax* sp. L.	1	2.0
Smilaceae	*Smilax tamnoides* L.	1	2.0
Solanaceae	*Solanum carolinense* L.	3	1.7 (0.5)
Ulmaceae	*Ulmus americana* L.	10	2.5 (0.7)
Urticaceae	*Boehmeria cylindrica* (L.) Sw.	1	1.0
Urticaceae	*Laportea canadensis* (L.) Benth.	1	37.0
Urticaceae	*Pilea pumila* (L.) A. Gray	7	16.0 (7.0)
Violaceae	*Viola sororia* Willd.	8	32.1 (6.6)
Violaceae	*Viola striata* Aiton	3	18.0 (13.1)
Vitaceae	*Parthenocissus quinquefolia* (L.) Planch.	29	14.3 (2.4)
Vitaceae	*Vitis vulpina* L.	8	1.5 (0.3)

were observed in the midstory plots (*Lonicera tatarica* L., *Elaeagnus umbellata* Thunb., and *Rosa multiflora* Thunb.), but they were much less common than *L. maackii*. *Fraxinus pennsylvanica* Marshall was the most frequent native species (Table 2).

Overstory Survey

We encountered 32 overstory species in 16 families (Table 3). Eleven plots had no overstory individuals within the 500 m^2 circular boundary. *Juglans nigra* L. was the most frequently occurring and most dominant species, resulting in being the top-ranked species by importance value (Table 3). The spatial arrangement of *J. nigra* we observed in the forest (not quantified) suggests it was planted by previous land owners and may not represent natural recruitment of the species—regular spacing, stems of equal size. Standing dead trees, which we treated as a single species, had the third highest importance value, outranking *Acer saccharum* Marshall due to frequency (Table 3).

Floristic Surveys

We conducted floristic surveys 18 times during the survey period, none of which individually covered the entire property. During the floristic surveys, we encountered an additional 137 species unique to the floristic survey – we did encounter 99 species shared with the ecological surveys (see Appendix 1). Several of the species found only during the floristic survey were of note, including eight species of Cyperaceae (sedges), two of Ophioglossaceae (adder's-tongue ferns), and three of Orchidaceae (orchids). While these were not necessarily rare, the were found because of the numerous visits with the floristic survey.

There were six species we could only identify to genus (Appendix 1). In each case, the individuals encountered were lacking key diagnostic characteristics and we were unable to confidently identify the species. It is possible that these specimens were actually the same as other species identified in the genera. Omitting

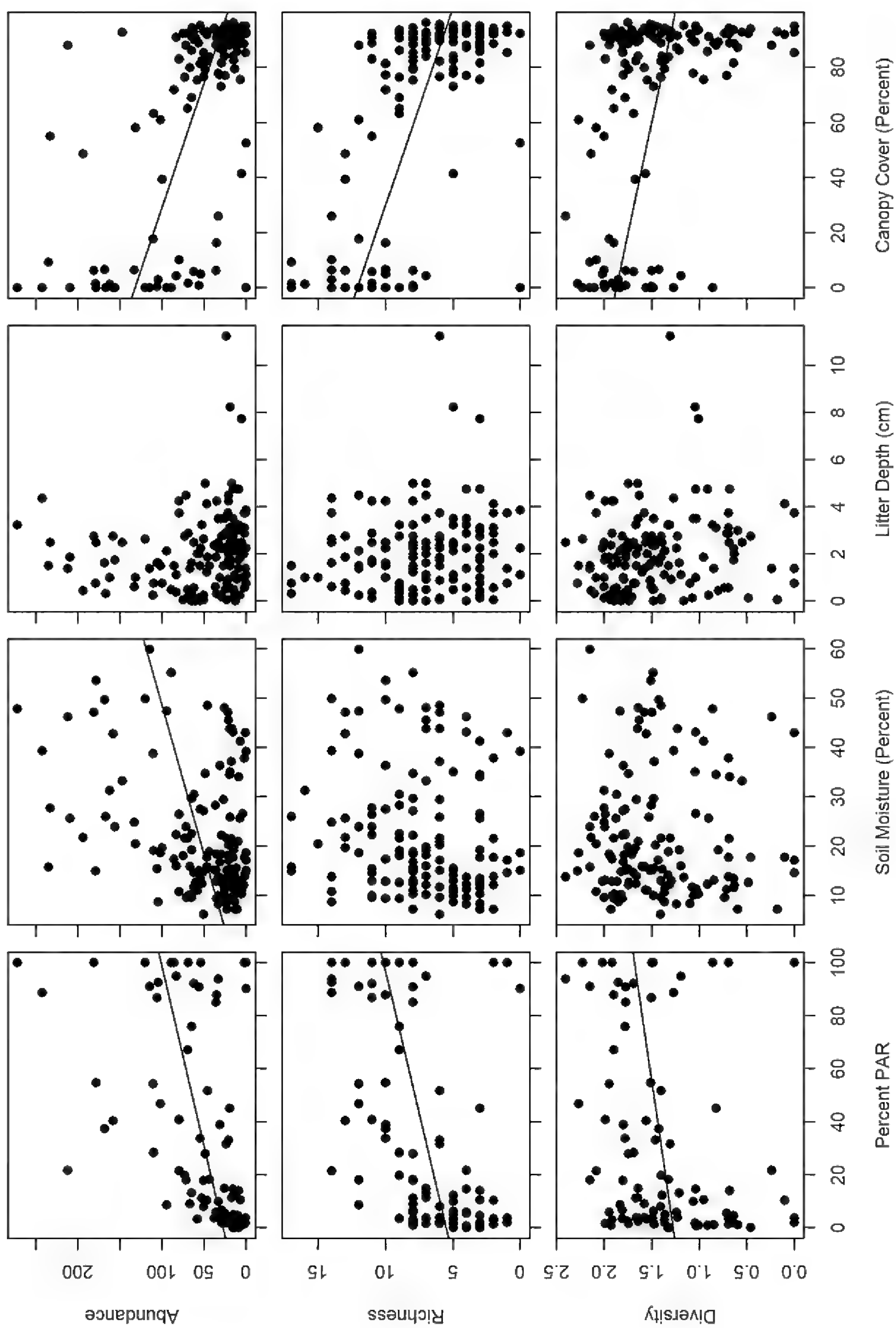

FIGURE 2. The relationships between understory abundance, richness, and diversity and environmental variables (the percentage of available photosynthetically active radiation [PAR], the percentage of volumetric soil moisture content, litter depth, and the percentage of canopy cover). Only significant relationships are represented by a line. The regression analysis included the survey month as a random effect.

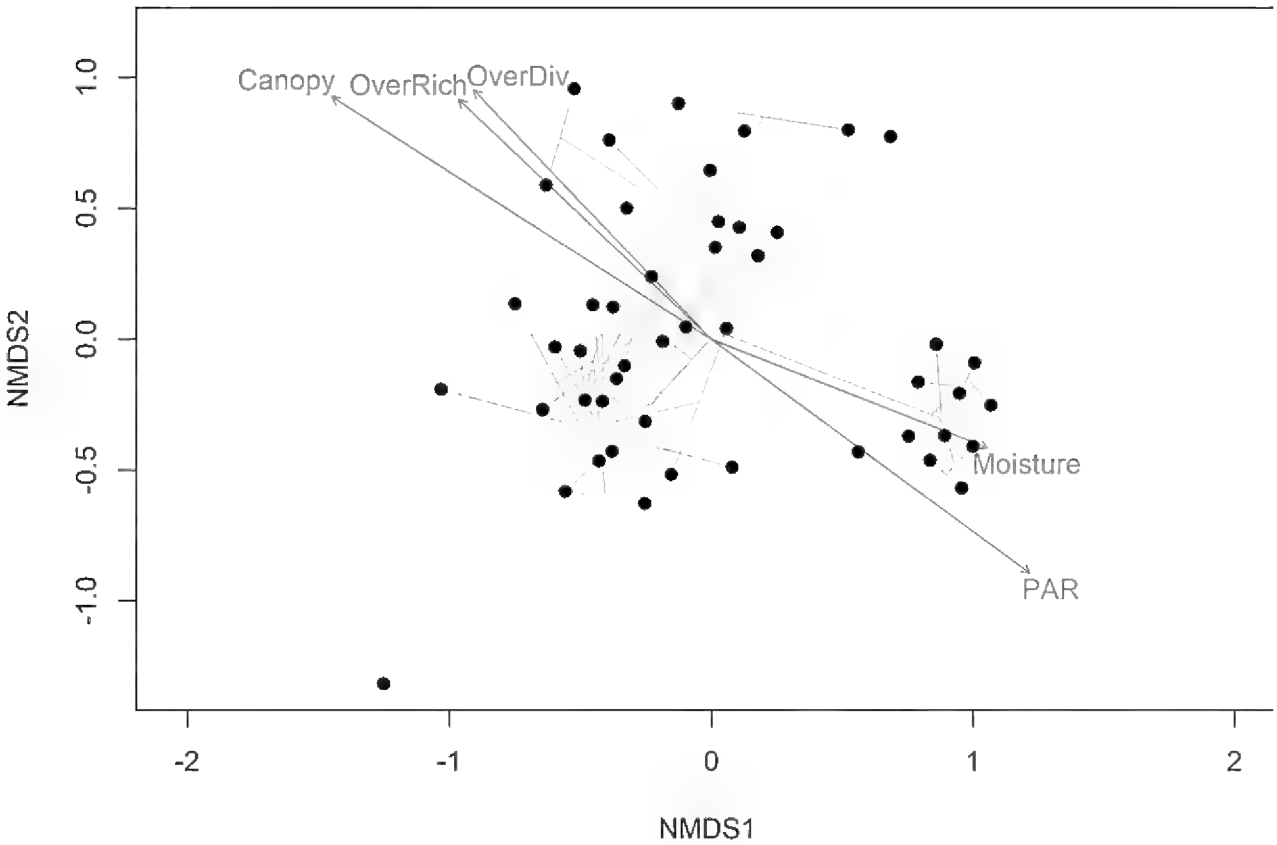

FIGURE 3. Nonmetric multidimensional scaling (NMDS) ordination of understory species based on stem counts within Little Wabash River Nature Preserve. Joint vectors represent relationships with environmental variables with an $R^2 > 0.2$; Canopy is percentage of overstory canopy cover, Moisture is the volumetric percentage of soil moisture content, PAR is the percentage of available photosynthetically active radiation, OverRich is overstory species richness, and OverDiv is the Shannon diversity index of overstory species. The light gray lines connecting points represent unweighted average linkage hierarchical clustering.

these six species only identified to genus, we encountered 251 species in the three strata (Appendix 1).

Only two species encountered at LWRNP had high C-values (i.e., intolerant of disturbance) –*Spiranthes magnicamporum* Sheviak (found in a subsequent visit in 2022) and *Taxodium distichum* (L.) Rich. var. *distichum* (Cupressaceae). Most species had a C-value of 6 or less (93.3% of those with assigned C-values). Approximately 17.3% of species did not have an assigned C-value due to being non-native species. The mean C-value for LWRNP was 2.89; based on 209 native species, LWRNP had an FQI of 41.56.

DISCUSSION

As most forests in northeast Indiana are relegated to disjunct fragments of a once-continuous forest, all well-established closed canopy forests represent important habitat for plants and animals in the region (Harman et al. 2019). Although LWRNP has a relatively open canopy (mean canopy cover = 71.5% across sampling dates in July and September), it is still an important part of the forest matrix in the region, and although it has clear evidence of past human ma-

TABLE 2. Species encountered in the midstory ecological surveys, the number of plots in which each occurred, and the mean number of individuals per plot (standard error in parentheses).

Family	Species name	Plots	Count
Adoxaceae	*Sambucus canadensis* L.	2	3.0 (2.0)
Cannabaceae	*Celtis occidentalis* L.	8	1.8 (0.4)
Caprifoliaceae	*Lonicera maackii* (Ruper.) Herder	30	11.6 (1.4)
Caprifoliaceae	*Lonicera tatarica* L.	3	5.0 (1.9)
Cornaceae	*Cornus drummondii* C.A. Mey.	10	3.9 (1.2)
Cornaceae	*Cornus racemosa* Lam.	6	3.3 (0.9)
Elaeagnaceae	*Elaeagnus umbellata* Thunb.	10	3.3 (1.0)
Fagaceae	*Quercus bicolor* Willd.	5	1.2 (0.2)
Fagaceae	*Quercus coccinea* Münchh.	1	1.0
Fagaceae	*Quercus rubra* L.	2	1.0
Juglandaceae	*Carya cordiformis* (Wangenh.) K. Koch	5	1.2 (0.2)
Juglandaceae	*Carya ovata* (Mill.) K. Koch	3	1.0
Juglandaceae	*Juglans nigra* L.	4	1.0
Oleaceae	*Fraxinus pennsylvanica* Marshall	18	4.4 (0.6)
Oleaceae	*Fraxinus quadrangulata* Michx.	3	3.7 (1.2)
Rosaceae	*Crataegus* sp. L.	1	7.0
Rosaceae	*Prunus serotina* Ehrh.	1	1.0
Rosaceae	*Prunus virginiana* L.	1	8.0
Rosaceae	*Rosa multiflora* Thunb.	1	2.0
Sapindaceae	*Aesculus glabra* Willd.	2	1.5 (0.4)
Sapindaceae	*Acer saccharum* Marshall	4	1.5 (0.4)
Ulmaceae	*Ulmus americana* L.	1	1.0
Ulmaceae	*Ulmus rubra* Muhl.	1	2.0

nipulation—e.g., winter aerial images display clear fence-line plantings of conifers, observed plantation patterns of *Juglans nigra*, occurrences of *Taxodium distichum* in the understory and overstory well beyond the northern range in the Midwest (Wilhite and Toliver 1990)—species of interest were nevertheless encountered.

We found three orchid species (Orchidaceae), two of which, *Liparis liliifolia* (L.) Rich. ex Ker Gawl. and *Spiranthes lacera* (Raf.) Raf. var. *gracilis* (Bigelow) Luer, have limited occurrence records in northeastern Indiana. These two orchid species, in addition to *Spiranthes cernua* (L.) Rich., have relatively low C-value (3), which indicates species that provide little or no confidence that its habitat signifies remnant conditions (Rothrock 2004). This suggests that they are adapted to habitats that are at least somewhat disturbed. Since they were found in a relatively disturbed portion of the property, management in that area to reduce overstory and midstory canopy, as well as to provide regular disturbance, will likely promote success in *L. liliifolia* and *S. lacera* var. *gracilis*, especially since closed canopy mature forest is not suitable habitat for these species (Morris 1989, Mattrick 2004). *Spiranthes magnicamporum* and *Spiranthes ovalis,* were observed during a subsequent site visit in 2022 as we were confirming the identification of *S. cernua*. We included *S. magnicamporum* and *S. ovalis* in Appendix 1 with the indication that they were observed outside of our original floristic survey dates.

Spiranthes magnicamporum (added in the subsequent visit in 2022) and *Tax-*

TABLE 3. Species encountered during the overstory ecological surveys and the frequency (number of plots), density (mean number of stems per plot) (standard error in parentheses), dominance (basal area in m^2/ha), and importance value (IV) of each.

Family	Species name	Frequency	Density	Dominance	IV
Altingaceae	*Liquidambar styraciflua* L.	5	2.7 (0.8)	0.70	3.43
Betulaceae	*Betula papyrifera* Marshall	1	1.0	0.05	0.76
Betulaceae	*Carpinus caroliniana* Walter	1	1.0	0.05	0.76
Betulaceae	*Ostrya virginiana* (Mill.) K. Koch	1	1.0	0.05	0.76
Cannabaceae	*Celtis occidentalis* L.	6	1.2 (0.3)	0.37	2.44
Cornaceae	*Cornus drummondii* C.A. Mey.	2	1.0	0.10	1.06
Cornaceae	*Cornus racemosa* Lam.	3	2.7 (1.4)	0.42	2.56
Cupressaceae	*Juniperus virginiana* L.	5	5.8 (2.2)	1.51	6.12
Cupressaceae	*Taxodium distichum* (L.) Rich.	1	4.0	0.21	2.39
Ebenaceae	*Diospyros virginiana* L.	1	3.0	0.16	1.85
Fagaceae	*Quercus alba* L.	1	1.0	0.05	0.76
Fagaceae	*Quercus bicolor* Willd.	15	4.3 (0.6)	3.34	10.46
Fagaceae	*Quercus coccinea* Münchh.	1	1.0	0.05	0.76
Fagaceae	*Quercus muehlenbergii* Engelm.	2	1.0	0.10	1.06
Fagaceae	*Quercus rubra* L.	10	1.6 (0.3)	0.83	4.22
Juglandaceae	*Carya cordiformis* (Wangenh.) K. Koch	4	2.9 (0.9)	0.60	3.15
Juglandaceae	*Carya ovata* (Mill.) K. Koch	6	1.4 (0.3)	0.44	2.65
Juglandaceae	*Juglans nigra* L.	20	4.0 (0.7)	4.20	12.76
Magnoliaceae	*Liriodendron tulipifera* L.	4	1.9 (0.9)	0.39	2.36
Oleaceae	*Fraxinus pennsylvanica* Marshall	7	1.3 (0.2)	0.47	2.87
Oleaceae	*Fraxinus quadrangulata* Michx.	2	2.0	0.21	1.69
Pinaceae	*Picea glauca* (Moench) Voss	1	3.0	0.16	1.85
Pinaceae	*Pinus strobus* L.	2	1.5 (0.4)	0.16	1.38
Rosaceae	*Crataegus* sp. L.	1	3.0	0.16	1.85
Rosaceae	*Prunus serotina* Ehrh.	10	3.6 (1.1)	1.85	6.73
Salicaeae	*Populus deltoides* W. Bartram ex Marshall	2	3.0 (0.7)	0.31	2.30
Sapindaceae	*Acer negundo* L.	1	1.0	0.05	0.76
Sapindaceae	*Acer saccharinum* L.	1	1.0	0.05	0.76
Sapindaceae	*Acer saccharum* Marshall	10	3.6 (0.8)	1.85	6.73
Sapindaceae	*Aesculus glabra* Willd.	1	2.0	0.10	1.30
Ulmaceae	*Ulmus americana* L.	7	1.9 (0.5)	0.70	3.50
Ulmaceae	*Ulmus rubra* Muhl.	1	1.0	0.05	0.76
	Dead trees	17	1.9 (0.3)	1.70	7.25

odium distichum were the only two species encountered at LWRNP that had a C-value of 10, the latter of which, as noted above, is outside its natural range at LWRNP. Only 6.7% of the species encountered in the ecological and floristic surveys had a C-value > 6; C-values of 6 and below are associated with species able to tolerate significant or moderate disturbance (Rothrock 2004). Wilhelm et al. (2003) suggested that habitats with Mean C-values of 2 or less are typically old fields and highly degraded sites. Additionally, habitats with Mean C-values of 5 or more would be sites characteristic of a pre-European settlement plant community (Rothrock 2004). The Mean C-value at LWRNP was 2.87, which further supports our interpretation that human influence has played a significant role at the site. This low Mean C-value suggests that there has been significant disturbance to the site, although it may not be fully degraded. FQI values are collinear with species richness (i.e., FQI values align with species richness and

are influenced by similar environmental factors), and Rooney and Rogers (2002) suggested using Mean C-value as a modified FQI value, which may be less influenced by the same environmental factors as species richness. Our FQI value at LWRNP (41.56) would suggest it is an exceptional site floristically, even with the extensive human influence of disturbance. This FQI value may be an overestimate of the floristic quality, however, the Mean C-value (2.87) may be an under-estimate of the floristic quality. By comparison, Fogwell Forest Nature Preserve (same county, 6.5 km away) has a Mean C-value of 3.60 and an FQI of 55.4, which has a plant community indicative of limited disturbance (Rothrock and Homoya 2005, Arvola et al. 2014). Rothrock (1997) noted the absence of non-native species were limited to the ecotone and old field and not in the core of the forest.

Even more evidence of the human influence at LWRNP was found in the midstory. Although there were only four non-native species in the midstory, they made up 65% of the total number of midstory individuals. The remaining 45% of midstory individuals belonged to 19 native species. The non-native *Lonicera maackii* accounted for 56% of all midstory individuals.

Long-term human impact on the plant community is evident in the overstory. Some of the overstory species with the five highest importance values were expected, while others were not. The overstory species with the highest importance value was *Juglans nigra*, which does not commonly dominate forests in northeastern Indiana, and Eyre (1980) does not define a Black Walnut forest type. The economic value of *J. nigra* likely led to the mass planting of this species by previous owners because it is currently among the highest values for sawlogs in Indiana (Settle and Gonso 2019). The species with the second and fourth highest importance values (*Quercus bicolor* Willd. and *Prunus serotina* Ehrh.) are known associates of *J. nigra* (Williams 1990). Standing dead trees had the third highest importance value in the overstory survey. These are essential in providing wildlife roosting sites and may provide insight into the relatively low percentage of canopy cover. *Acer saccharum* L., which shared the fourth highest importance value with *P. serotina*, is commonly the dominant species in second-growth forests in northeastern Indiana (e.g., Arvola et al. 2014, Bisht et al. 2017, Harman et al. 2019), which is why its lower rank at LWRNP was surprising.

Overall, LWRNP provides habitat to a relatively large pool of plant species (251 species across the three strata). Due to fragmentation, isolation, and diminished size of forests in the region, this property is of importance to preserving species and habitat. LWRNP provides an example of the plant diversity can exist in a small, protected forest. While the forest has been manipulated and its community structure dominated by human influence, there is still conservation value in continued protection of this site.

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APPENDIX 1. Full list of species encountered at Little Wabash River Nature Preserve in the ecological surveys (column E) and the floristic surveys (column F). Family and scientific names follow ITIS (2023). Non-native species are indicated with a dagger (†) preceding the scientific name. Presence of a species in corresponding surveys is indicated with an 'X'. Presence in a floristic survey in a subsequent visit in 2022 is indicated by an asterisk (*). The voucher numbers refer to specimens deposited in the Purdue University Fort Wayne Department of Biological Sciences herbarium.

Family	Scientific name	E	F	Voucher Number
Adoxaceae	*Sambucus canadensis* L.	X	X	LWRNP0109
Alismataceae	*Alisma subcordatum* Raf.		X	LWRNP0077
Altingiaceae	*Liquidambar styraciflua* L.		X	
Amaryllidaceae	*Allium tricoccum* Sol. var. *burdickii* Hanes		X	LWRNP0137
Anacardiaceae	*Rhus glabra* L.		X	
Anacardiaceae	*Rhus typhina* L.		X	LWRNP0110
Anacardiaceae	*Toxicodendron radicans* (L.) Kuntze	X	X	
Annonaceae	*Asimina triloba* (L.) Dunal		X	
Apiaceae	*Cryptotaenia canadensis* (L.) DC.	X	X	LWRNP0051
Apiaceae	†*Daucus carota* L.	X	X	LWRNP0139
Apiaceae	*Erigenia bulbosa* (Michx.) Nutt.	X	X	LWRNP0003
Apiaceae	*Osmorhiza claytonii* (Michx.) C.B. Clarke	X		
Apiaceae	*Osmorhiza longistylis* (Torr.) DC.		X	LWRNP0224
Apiaceae	†*Pastinaca sativa* L.	X		

APPENDIX 1. (*Continued*).

Family	Scientific name	E	F	Voucher Number
Apiaceae	*Sanicula canadensis* L.	X	X	LWRNP0093
Apocynaceae	*Apocynum cannabinum* L.	X	X	LWRNP0108
Apocynaceae	*Asclepias incarnata* L.		X	
Apocynaceae	*Asclepias quadrifolia* Jacq.		X	
Apocynaceae	*Asclepias syriaca* L.	X	X	LWRNP0078
Araceae	*Arisaema triphyllum* (L.) Schott		X	LWRNP0031
Asparagaceae	†*Asparagus officinalis* L.		X	LWRNP0174
Asparagaceae	†*Convallaria majalis* L.	X	X	LWRNP0043
Asparagaceae	*Maianthemum racemosum* (L.) Link	X	X	LWRNP0053
Asparagaceae	*Polygonatum biflorum* (Walter) Elliott	X	X	LWRNP0047
Aspleniaceae	*Asplenium platyneuron* (L.) Britton, Sterns & Poggenb.	X	X	
Asteraceae	*Achillea millefolium* L.		X	LWRNP0144
Asteraceae	*Ageratina altissima* (L.) R.M. King & H. Rob	X	X	LWRNP0189
Asteraceae	*Ambrosia artemisiifolia* L.	X	X	LWRNP0193
Asteraceae	*Ambrosia trifida* L.		X	
Asteraceae	*Antennaria parlinii* Fernald subsp. *fallax* (Greene) R.J. Bayer & Stebbins		X	LWRNP0012
Asteraceae	†*Arctium minus* (Hill) Bernh.	X		
Asteraceae	*Bidens frondosa* L.		X	LWRNP0232
Asteraceae	†*Cichorium intybus* L.		X	
Asteraceae	†*Cirsium arvense* (L.) Scop.	X	X	LWRNP0083
Asteraceae	†*Cirsium vulgare* (Savi) Ten.		X	
Asteraceae	*Eclipta prostrata* (L.) L.		X	LWRNP0239
Asteraceae	*Erigeron annuus* (L.) Pers.	X	X	LWRNP0237
Asteraceae	*Erigeron philadelphicus* L.		X	LWRNP0241
Asteraceae	*Eupatorium perfoliatum* L.		X	LWRNP0238
Asteraceae	*Euthamia graminifolia* (L.) Nutt.	X	X	LWRNP0236
Asteraceae	*Eutrochium maculatum* (L.) E.E. Lamont		X	
Asteraceae	*Helianthus decapetalus* L.		X	LWRNP0240
Asteraceae	†*Hemerocallis fulva* (L.) L.		X	LWRNP0087
Asteraceae	†*Hieracium piloselloides* Vill.		X	LWRNP0023
Asteraceae	*Lactuca biennis* (Moench) Fernald		X	LWRNP0185
Asteraceae	†*Leucanthemum vulgare* Lam.	X	X	LWRNP0170
Asteraceae	*Packera glabella* (Poir) C. Jeffrey	X		
Asteraceae	*Solidago altissima* L.	X	X	LWRNP0235
Asteraceae	*Solidago canadensis* L. var. *hargeri* Fernald	X	X	LWRNP0234
Asteraceae	*Solidago* sp.	X		
Asteraceae	*Symphyotrichum cordifolium* (L.) G.L. Nesom		X	LWRNP0243
Asteraceae	*Symphyotrichum lanceolatum* (Willd.) G.L. Nesom	X	X	LWRNP0165
Asteraceae	*Symphyotrichum lateriflorum* (L.) Á. Löve & D. Löve		X	LWRNP0242
Asteraceae	*Symphyotrichum novae-angliae* (L.) G.L. Nesom		X	LWRNP0156
Asteraceae	*Symphyotrichum pilosum* (Willd.) G.L. Nesom		X	LWRNP0168
Asteraceae	*Symphyotrichum shortii* (Lindl.) G.L. Nesom	X	X	LWRNP0157
Asteraceae	†*Taraxacum officinale* F.H. Wigg.	X	X	LWRNP0227
Asteraceae	*Verbesina alternifolia* (L.) Britton ex Kearney		X	
Asteraceae	*Vernonia gigantea* (Walter) Trel.	X	X	LWRNP0230
Balsaminaceae	*Impatiens capensis* Meerb.	X	X	LWRNP0138
Berberidaceae	*Podophyllum peltatum* L.		X	LWRNP0049
Betulaceae	*Betula papyrifera* Marshall		X	
Betulaceae	*Carpinus caroliniana* Walter		X	LWRNP0197
Betulaceae	*Ostrya virginiana* (Mill.) K. Koch		X	LWRNP0121

(*Continued on next page*)

APPENDIX 1. (*Continued*).

Family	Scientific name	E	F	Voucher Number
Boraginaceae	*Hackelia virginiana* (L.) I.M. Johnst.		X	LWRNP0141
Brassicaceae	†*Alliaria petiolata* (M. Bieb.) Cavara & Grande	X	X	LWRNP0036
Brassicaceae	†*Barbarea vulgaris* W.T. Aiton		X	LWRNP0213
Brassicaceae	†*Brassica nigra* (L.) W.D.J. Koch		X	
Brassicaceae	*Cardamine concatenata* (Michx.) Sw.	X	X	LWRNP0006
Brassicaceae	*Cardamine douglassii* Britton	X	X	LWRNP0015
Brassicaceae	†*Lepidium campestre* (L.) W.T. Aiton	X	X	LWRNP0035
Campanulaceae	*Campanulastrum americanum* (L.) Small		X	LWRNP0132
Campanulaceae	*Lobelia inflata* L.		X	LWRNP0175
Campanulaceae	*Lobelia siphilitica* L.		X	LWRNP0195
Cannabaceae	*Celtis occidentalis* L.	X	X	LWRNP0113
Caprifoliaceae	†*Lonicera maackii* (Rupr.) Herder	X	X	LWRNP0074
Caprifoliaceae	†*Lonicera* sp.		X	LWRNP0112
Caryophyllaceae	†*Cerastium fontanum* Baumg.	X	X	LWRNP0177
Caryophyllaceae	†*Dianthus armeria* L.		X	LWRNP0204
Caryophyllaceae	†*Stellaria media* (L.) Vill.	X	X	LWRNP0225
Celastraceae	*Euonymus atropurpureus* Jacq.	X		
Convulvulaceae	†*Calystegia silvatica* (Kit.) Griseb.		X	LWRNP0167
Cornaceae	*Cornus drummondii* C.A. Mey	X	X	LWRNP0104
Cornaceae	*Cornus racemosa* Lam.	X	X	LWRNP0084
Cucurbitaceae	*Echinocystis lobata* (Michx.) Torr. & A. Gray		X	LWRNP0172
Cupressaceae	*Juniperus virginiana* L.		X	
Cupressaceae	*Taxodium distichum* (L.) Rich. var. *distichum*		X	
Cyperaceae	*Carex blanda* Dewey		X	LWRNP0194
Cyperaceae	*Carex granularis* Muhl. ex Willd.	X	X	LWRNP0181
Cyperaceae	*Carex hirtifolia* Mack.		X	LWRNP0190
Cyperaceae	*Carex jamesii* Schwein.	X	X	LWRNP0044
Cyperaceae	*Carex laevivaginata* (Kük.) Mack.		X	LWRNP0082
Cyperaceae	*Carex normalis* Mack.	X	X	LWRNP0183
Cyperaceae	*Carex oligocarpa* Schkuhr ex Willd.		X	LWRNP0208
Cyperaceae	*Carex rosea* Schkuhr ex Willd.		X	LWRNP0199
Cyperaceae	*Carex shortiana* Dewey		X	LWRNP0179
Cyperaceae	*Carex sparganioides* Muhl. ex Willd.		X	LWRNP0205
Cyperaceae	*Carex stipata* Muhl. ex Willd.	X	X	LWRNP0196
Cyperaceae	*Carex tribiloides* Wahlenb.		X	
Cyperaceae	*Carex vulpinoidea* Michx.	X	X	LWRNP0201
Cyperaceae	*Scirpus atrovirens* Willd.	X	X	LWRNP0130
Dioscoreaceae	*Dioscorea villosa* L.		X	
Dryopteridaceae	*Dryopteris carthusiana* (Vill.) H.P. Fuchs		X	LWRNP0056
Dryopteridaceae	*Polystichum acrostichoides* (Michx.) Schott		X	LWRNP0055
Ebenaceae	*Diospyros virginiana* L.		X	
Elaeagnaceae	†*Elaeagnus umbellata* Thunb.	X	X	LWRNP0026
Equisetaceae	*Equisetum arvense* L.		X	LWRNP0009
Ericaceae	*Monotropa uniflora* L.		X	LWRNP0192
Fabaceae	*Amphicarpaea bracteata* (L.) Fernald		X	LWRNP0166
Fabaceae	*Cercis canadensis* L.	X	X	LWRNP0118
Fabaceae	*Desmodium paniculatum* (L.) DC.		X	LWRNP0202
Fabaceae	*Gleditsia triacanthos* L.		X	LWRNP0101
Fabaceae	†*Medicago sativa* L.	X		
Fabaceae	†*Securigera varia* (L.) Lassen		X	LWRNP0114
Fabaceae	†*Trifolium pratense* L.	X	X	LWRNP0052
Fabaceae	†*Trifolium repens* L.	X	X	LWRNP0146
Fagaceae	*Quercus alba* L.	X	X	

APPENDIX 1. (*Continued*).

Family	Scientific name	E	F	Voucher Number
Fagaceae	*Quercus bicolor* Willd.	X	X	LWRNP0075
Fagaceae	*Quercus coccinea* Münchh.		X	
Fagaceae	*Quercus muehlenbergii* Engelm.		X	
Fagaceae	*Quercus rubra* L.	X	X	LWRNP0091
Papaveraceae	*Dicentra canadensis* (Goldie) Walp.		X	LWRNP0008
Papaveraceae	*Dicentra cucullaria* (L.) Bernh.		X	LWRNP0001
Geraniaceae	*Geranium maculatum* L.	X	X	LWRNP0038
Grossulariaceae	*Ribes cynosbati* L.	X	X	LWRNP0014
Hydrophyllaceae	*Hydrophyllum appendiculatum* Michx.	X	X	LWRNP0048
Hydrophyllaceae	*Hydrophyllum macrophyllum* Nutt.	X	X	LWRNP0057
Hydrophyllaceae	*Hydrophyllum virginianum* L.		X	LWRNP0218
Hydrophyllaceae	*Phacelia bipinnatifida* Michx.		X	
Hypericaceae	†*Hypericum perforatum* L.		X	LWRNP0134
Hypericaceae	*Hypericum punctatum* Lam.		X	LWRNP0217
Iridaceae	*Sisyrinchium angustifolium* Mill.		X	LWRNP0028
Juglandaceae	*Carya cordiformis* (Wangenh.) K. Koch	X	X	
Juglandaceae	*Carya ovata* (Mill.) K. Koch		X	
Juglandaceae	*Juglans nigra* L.		X	
Juncaceae	*Juncus tenuis* Willd.	X	X	LWRNP0067
Lamiaceae	*Agastache nepetoides* L.		X	LWRNP0184
Lamiaceae	*Blephilia hirsuta* (Pursh) Benth.	X		
Lamiaceae	*Collinsonia canadensis* L.		X	LWRNP0182
Lamiaceae	†*Glechoma hederacea* L.	X	X	LWRNP0050
Lamiaceae	*Lycopus americanus* Muhl. ex W.P.C. Barton		X	LWRNP0200
Lamiaceae	*Monarda fistulosa* L.		X	LWRNP0097
Lamiaceae	*Monarda serotina nom. illeg.*		X	LWRNP0250
Lamiaceae	†*Origanum vulgare* L.		X	LWRNP0088
Lamiaceae	*Prunella vulgaris* L.	X	X	LWRNP0090
Lamiaceae	*Stachys tenuifolia* Willd.		X	LWRNP0224
Lamiaceae	*Teucrium canadense* L.		X	LWRNP0092
Lauraceae	*Lindera benzoin* (L.) Blume		X	LWRNP0158
Liliaceae	*Erythronium albidum* Nutt.		X	LWRNP0007
Liliaceae	*Erythronium americanum* Ker Gawl.	X	X	LWRNP0002
Limnanthaceae	*Floerkea proserpinacoides* Willd.	X	X	LWRNP0032
Magnoliaceae	*Liriodendron tulipifera* L.		X	LWRNP0073
Malvaceae	*Tilia americana* L.		X	LWRNP0105
Melanthiaceae	*Trillium sessile* L.		X	LWRNP0010
Menispermaceae	*Menispermum canadense* L.	X	X	LWRNP0058
Montiaceae	*Claytonia virginica* L.	X	X	LWRNP0005
Moraceae	†*Morus nigra* L.		X	
Moraceae	*Morus rubra* L.		X	LWRNP0020
Myrsinaceae	*Lysimachia quadrifolia* L.		X	LWRNP0122
Oleaceae	*Fraxinus pennsylvanica* Marshall	X		
Oleaceae	*Fraxinus quadrangulata* Michx.	X	X	LWRNP0159
Onagraceae	*Circaea canadensis* (L.) Hill	X	X	LWRNP0145
Onagraceae	*Circaea lutetiana* L.	X		
Onagraceae	*Epilobium coloratum* Biehler		X	LWRNP0169
Onagraceae	*Ludwigia palustris* (L.) Elliott		X	LWRNP0215
Onocleaceae	*Onoclea sensibilis* L.		X	LWRNP0054
Ophioglossaceae	*Botrychium virginianum* (L.) Sw.		X	LWRNP0080
Ophioglossaceae	*Ophioglossum vulgatum* L.		X	LWRNP0076
Orchidaceae	*Liparis liliifolia* (L.) Rich. ex Ker Gawl.		X	

(*Continued on next page*)

APPENDIX 1. (*Continued*).

Family	Scientific name	E	F	Voucher Number
Orchidaceae	*Spiranthes cernua* (L.) Rich.		X	LWRNP0251
Orchidaceae	*Spiranthes lacera* (Raf.) Raf. var. *gracilis* (Bigelow) Luer		X	LWRNP0162
Orchidaceae	*Spiranthes magnicamporum* Sheviak		*	
Orchidaceae	*Spiranthes ovalis* Lind.		*	
Oxalidaceae	*Oxalis dillenii* Jacq.	X	X	LWRNP0143
Papaveraceae	*Sanguinaria canadensis* L.		X	
Penthoraceae	*Penthorum sedoides* L.		X	LWRNP0149
Phrymaceae	*Mimulus ringens* L.		X	LWRNP0180
Phrymaceae	*Phryma leptostachya* L.	X	X	LWRNP0136
Phytolaccaceae	*Phytolacca americana* L.		X	LWRNP0178
Pinaceae	*Picea glauca* (Moench) Voss		X	
Pinaceae	*Pinus strobus* L.	X	X	
Plantaginaceae	†*Plantago lanceolata* L.	X	X	LWRNP0024
Plantaginaceae	*Plantago rugelii* Decne.	X		
Plantaginaceae	†*Veronica serpyllifolia* L. subsp. *serpyllifolia*		X	LWRNP0220
Platanaceae	*Platanus occidentalis* L.		X	
Poaceae	†*Agrostis gigantea* Roth	X	X	LWRNP0207
Poaceae	†*Bromus inermis* Leyss.		X	LWRNP0216
Poaceae	*Bromus pubescens* Muhl. ex Willd.	X	X	LWRNP0081
Poaceae	†*Dactylis glomerata* L.	X	X	LWRNP0210
Poaceae	*Dichanthelium boscii* (Poir.) Gould & C.A. Clark	X	X	LWRNP0085
Poaceae	*Dichanthelium linearifolium* (Scribn. ex Nash) Gould	X		
Poaceae	†*Echinochloa crus-galli* (L.) P. Beauv.		X	
Poaceae	*Elymus canadensis* L.		X	LWRNP0071
Poaceae	*Elymus hystrix* L.	X	X	LWRNP0129
Poaceae	*Elymus virginicus* L. var. *virginicus*		X	LWRNP0209
Poaceae	*Glyceria striata* (Lam.) Hitchc.	X	X	LWRNP0249
Poaceae	*Leersia virginica* Willd.		X	LWRNP0219
Poaceae	†*Phleum pratense* L.	X	X	LWRNP0068
Poaceae	†*Poa pratensis* L. subsp. *pratensis*	X	X	LWRNP0221
Poaceae	*Poa sylvestris* A. Gray	X	X	LWRNP0223
Polemoniaceae	*Phlox divaricata* L.		X	LWRNP0039
Polemoniaceae	*Polemonium reptans* L.		X	LWRNP0037
Polygonaceae	*Fallopia scandens* (L.) Holub		X	LWRNP0173
Polygonaceae	*Persicaria punctata* (Elliott) Small		X	LWRNP0247
Polygonaceae	*Persicaria virginiana* (L.) Gaertn	X	X	LWRNP0176
Primulaceae	*Lysimachia ciliata* L.		X	LWRNP0229
Ranunculaceae	*Actaea pachypoda* Elliott	X	X	LWRNP0046
Ranunculaceae	*Anemone canadensis* L.	X		
Ranunculaceae	*Ranunculus abortivus* L.	X	X	LWRNP0016
Ranunculaceae	†*Ranunculus ficaria* L.		X	LWRNP0030
Ranunculaceae	*Ranunculus hispidus* Michx.		X	LWRNP0045
Ranunculaceae	*Ranunculus recurvatus* Poir.	X	X	LWRNP0017
Rosaceae	*Agrimonia pubescens* Wallr.		X	LWRNP0228
Rosaceae	*Crataegus* sp.		X	LWRNP0233
Rosaceae	†*Duchesnea indica* (Andrews) Focke var. *indica*	X		
Rosaceae	*Fragaria vesca* L.	X		
Rosaceae	*Fragaria vesca* L. subps. *vesca*	X		
Rosaceae	*Fragaria virginiana* Duchesne subsp. *grayana* (E. Vilm. ex J. Gray) Staudt		X	LWRNP0059
Rosaceae	*Geum canadense* Jacq.	X	X	LWRNP0065
Rosaceae	*Geum* sp.	X		

APPENDIX 1. (*Continued*).

Family	Scientific name	E	F	Voucher Number
Rosaceae	*Geum vernum* (Raf.) Torr. & A. Gray	X	X	LWRNP0040
Rosaceae	†*Potentilla recta* L.		X	LWRNP0135
Rosaceae	*Prunus serotina* Ehrh.	X	X	LWRNP0107
Rosaceae	†*Rosa multiflora* Thunb.	X	X	LWRNP0212
Rosaceae	*Rosa setigera* Michx. var. *tomentosa* Torr. & A. Gray		X	LWRNP0246
Rosaceae	*Rosa* sp.		X	LWRNP0248
Rosaceae	*Rubus occidentalis* L.	X	X	LWRNP0211
Rubiaceae	*Galium aparine* L.	X	X	LWRNP0061
Rubiaceae	*Galium asprellum* Michx.	X		
Rubiaceae	*Galium circaezans* Michx.	X	X	LWRNP0063
Rubiaceae	*Galium concinnum* Torr. & A. Gray	X	X	LWRNP0086
Rubiaceae	*Galium triflorum* Michx.	X	X	LWRNP0119
Salicaceae	*Populus deltoides* W. Bartram ex Marshall		X	
Salicaceae	*Salix nigra* Marshall		X	LWRNP0111
Sapindaceae	*Acer negundo* L.		X	LWRNP0198
Sapindaceae	*Acer saccharinum* L.		X	
Sapindaceae	*Acer saccharum* Marshall	X	X	LWRNP0019
Sapindaceae	*Aesculus glabra* Willd.	X	X	LWRNP0072
Scrophulariaceae	*Scrophularia marilandica* L.		X	
Smilacaceae	*Smilax ecirrhata* S. Watson		X	LWRNP0100
Smilacaceae	*Smilax* sp.	X		
Smilaceae	*Smilax tamnoides* L.	X	X	LWRNP0226
Solanaceae	*Physalis longifolia* Nutt.		X	LWRNP0131
Solanaceae	*Solanum carolinense* L.	X	X	LWRNP0245
Ulmaceae	*Ulmus americana* L.	X	X	LWRNP0120
Ulmaceae	*Ulmus rubra* Muhl.		X	LWRNP0152
Urticaceae	*Boehmeria cylindrica* (L.) Sw.	X	X	LWRNP0186
Urticaceae	*Laportea canadensis* (L.) Benth.	X	X	
Urticaceae	*Pilea pumila* (L.) A. Gray	X	X	LWRNP0140
Urticaceae	*Urtica dioica* L.		X	
Verbenaceae	*Verbena urticafolia* L.		X	
Violaceae	*Viola pubescens* Aiton		X	LWRNP0011
Violaceae	*Viola sororia* Willd.	X	X	LWRNP0095
Violaceae	*Viola striata* Aiton	X	X	LWRNP0093
Vitaceae	*Parthenocissus quinquefolia* (L.) Planch.	X	X	LWRNP0034
Vitaceae	*Vitis vulpina* L.	X	X	LWRNP0222

NOTEWORTHY COLLECTIONS

DISJUNCT OCCURRENCES OF *BOTRYCHIUM CRENULATUM* W. H. WAGNER (OPHIOGLOSSACEAE) IN NORTHWESTERN MINNESOTA, USA.

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Significance of Report. Populations of *Botrychium crenulatum* discovered in northwestern Minnesota since 2011 are over 1000 km disjunct from the nearest previously known populations; they occur in two distinctly different kinds of habitat where they exhibit two extremes of morphology.

Previous Knowledge. Since its description in 1981, *Botrychium crenulatum* W. H. Wagner (Dainty moonwort) has been found to be widely distributed in western North America from southern California and Arizona to British Columbia and Alberta. Even so, the species is less common than most species of *Botrychium* (moonworts) throughout this range. It is the most hydrophilic of the moonworts, occurring in saturated soils of spring seeps, riparian margins, and hardwater fens (Farrar, 2011). Although it was originally presumed to be limited to western North America, Farrar (2011) noted one disjunct occurrence that was then newly discovered in June 2011 in Itasca County, Minnesota, and noted others in the James Bay region of Ontario. More recently, he reports abundant populations in western Newfoundland where it can be the most common moonwort (Farrar, personal communication).

Botrychium crenulatum was first collected in Minnesota by Otto Gockman in Chippewa National Forest, Itasca County, north of Lake Winnibigoshish. The habitat is the seasonally saturated marshland margin of a northern mixed hardwood forest (Figure 1). The plants were growing in nearly full shade under a canopy locally dominated by *Fraxinus nigra* Marshall. They are small and with a very delicate habit (Figure 2). Other moonworts at the site include *B. minganense* Vict., *B. ascendens* W. H. Wagner, *B. pallidum* W. H. Wagner, and, in mixed hardwoods in close proximity, *B. mormo* W. H. Wagner. This is a common habitat in Chippewa National Forest, but ongoing surveys of similar sites have yet to find additional populations of *B. crenulatum* (Bobby Henderson, personal communication).

Discussion. In 2015 and 2017, I made collections from two populations of *Botrychium crenulatum* in Lake of the Woods and Roseau counties. The two sites are separated by approximately 31 km and are approximately 160 km northwest of the Itasca County site. They are roughly equally distant, at over 1000 km, from both the nearest western distribution of the species and the James Bay

FIGURE 1. *Botrychium crenulatum* habitat at the Chippewa National Forest site in Itasca County, a seasonally saturated marshland margin of northern mixed hardwood forest, under a canopy locally dominated by *Fraxinus nigra*. Photo by Richard Haug.

region occurrences. These sites are on the well-drained, sandy soils of old periglacial Lake Agassiz beach ridges that cross the landscape between large peatland basins. Due to an unusual landscape history described in North et al. (2013) and MacFarlane and MacFarlane (2021), the most productive *Botrychium* habitats here are now on old-field and homestead sites abandoned precipitously in the 1930s. This is true for all species of *Botrychium* known to occur here. This savannah region is marginally north and west of the known ranges of the forest moonwort species, *B. mormo* and *B. angustisegmentum* (Pease & A. H. Moore) Fernald. These sites are mesic to seasonally dry, which may modify what we consider suitable habitat for *B. crenulatum* in Minnesota. *Botrychium crenulatum* specimens were confirmed by Don Farrar on site visits, June 25 and 26, 2022, from an old-field site in southeastern Roseau County (Figure 3) and a homestead site in southern Lake of the Woods County (Figure 4).

On these sites, *Botrychium crenulatum* occurs in genus communities of at least three species, most abundantly *B. neolunaria* Stensvold & Farrar, *B. minganense,* and *B. pallidum.* Populations are in partial shade under small *Populus tremuloides* Michx., mature *Acer negundo* L., or dense clumps of *Bromus inermis* Leyss. These habitats produce very robust plants (Figure 5) compared to the

FIGURE 2. *Botrychium crenulatum* from the Chippewa National Forest site in Itasca County. Photo by Malcolm MacFarlane.

FIGURE 3. *Botrychium crenulatum* habitat at the Hayes Lake site, Roseau County, in old field on dry, sandy soil in sparse grasses under *Acer negundo*. Photo by Malcolm MacFarlane.

FIGURE 4. *Botrychium crenulatum* habitat at the Hogsback site, Red Lake Wildlife Management Area, Lake of the Woods County, on an abandoned homestead in a dense stand of *Bromus inermis*. Photo by Malcolm MacFarlane.

Itasca County plants, which suggests that these may be more favorable habitats for *Botrychium crenulatum* in Minnesota. Due to what was presumed an unusual, even inhospitable, habitat for this relatively hydrophilic species, the very robust habit, and the co-occurrence of two morphologically similar species, *B. neolunaria* and *B. minganense*, specimens from the Lake of the Woods County population were initially overlooked as aberrant specimens of *B. neolunaria.* Then the Roseau County population was found, which had a greater proportion of *B. crenulatum* and with a very consistent morphology. This was the drier of the two sites. Figure 6 is a detail of two pressed specimens from each of these two sites. There are other mixed populations of *B. neolunaria* and *B. minganense* I have collected from in this region since 2013 that could include *B. crenulatum* as well. Collections from these populations were not sufficiently mature to reliably distinguish between *B. neolunaria* and *B. crenulatum.* These sites will be revisited to check specifically for *B. crenulatum.*

The Minnesota occurrences and those in the James Bay region and in western Newfoundland suggest an earlier, more continuous post-glacial distribution that was trans-continental. Such a distribution may persist across central Canada and may include habitats not previously considered suitable for this species.

Diagnostic Characteristics. *Botrychium crenulatum* is described in Wagner and Wagner (1981). Additional observations were offered by Don Farrar during field site visits in 2022. Two moonwort species in Minnesota may have basal pinnae with a span of nearly a half circle, *Botrychium neolunaria* and *B. crenu-*

FIGURE 5. *Botrychium crenulatum* from the Hayes Lake site in Roseau County. Photo by Welby Smith.

latum. Specimens of *B. crenulatum* with narrower pinnae may look much like *B. minganense.* These three species are both similar enough and variable enough that the differences between them may be subtle. Thus, the characteristics should be considered more as population characteristics rather than necessarily applicable in every specific instance to every individual. Robust specimens of *B. crenulatum* from northwestern Minnesota look much like *B. neolunaria,* while daintier specimens like the Itasca County plants may more closely resemble *B. minganense*.

Botrychium crenulatum in Minnesota typically has a stalked trophophore and slightly ascending pinnae with crenulate margins. The pinna pairs are usually well separated as compared to *B. neolunaria*, which commonly has more proximate, or even overlapping, pinna pairs. In *B. neolunaria*, subsequent pinna pairs are often increasingly ascending from the first to the third pair, while in *B. crenulatum,* they are more consistently ascending throughout. Robust specimens of *B. crenulatum* may have lower pinnae that are deeply incised up to half their length into three to five or more sections, each usually with somewhat crenulate margins (Figure 6). At maturity (i.e., at spore release), the sporophore stalk of *B. crenulatum* is approximately the same length as the trophophore, which is shorter than is typical for *B. neolunaria.* The sporophore branches of *B. crenulatum* occupy approximately half the length of the sporophore and are spreading,

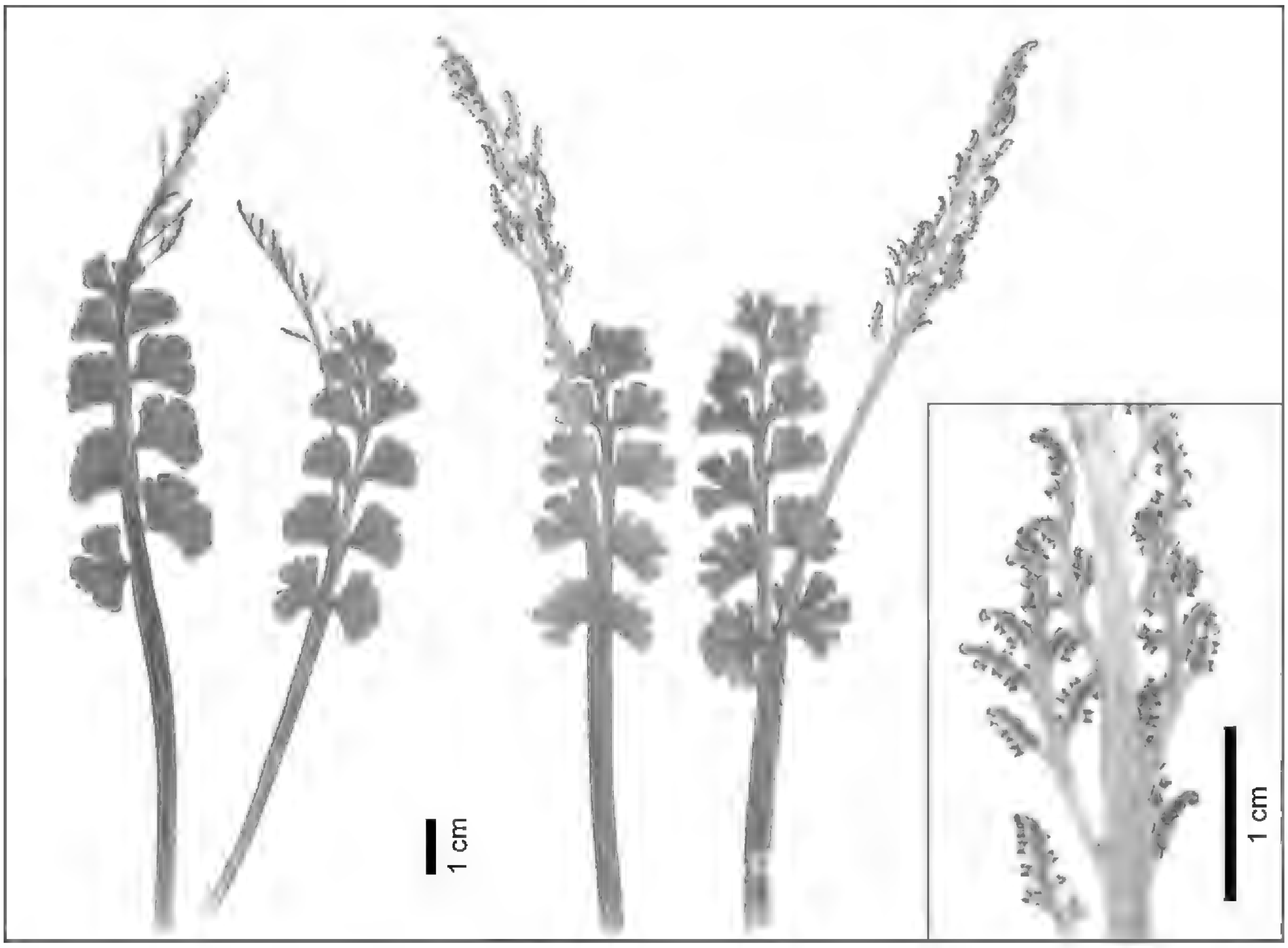

FIGURE 6. Detail of mature pressed specimens of *Botrychium crenulatum* from collections in north-northwestern Minnesota, June 26 and 27, 2022. Two specimens on the left are from the Hogsback site, Red Lake Wildlife Management area, Lake of the Woods County. Two specimens on the right are from the Hayes Lake site, Hayes Lake State Park, Roseau County. Photo by Richard Haug.

while those of *B. neolunaria* are more crowded into the upper third of the sporophore and are more ascending. The sporophore branches of *B. crenulatum* commonly twist (Figure 5), directing the sporangia outward or downward.

Botrychium minganense shares the traits of a stalked trophophore, well separated pinna pairs, consistently ascending pinnae (although significantly more so than *B. crenulatum*), and sporophore stalks approximately equal to the length of the trophophore. The pinna margins in *B. minganense* tend to be entire to lobed, but are notoriously variable.

Specimen Citations. MINNESOTA, Itasca County, Chippewa National Forest/Leech Lake Indian Reservation, south of Hale Lake, T147N, R28W, Sec. 25. A sparse population in a 10 × 30 m area in seasonally saturated marshland margin of northern mixed hardwood forest, in full shade, under canopy locally dominated by *Fraxinus nigra.* Associates include *Botrychium minganense, B. ascendens,* and *B. pallidum.* June 30, 2011, *Otto Gockman 00049* (MIN) 53607[1305435].

MINNESOTA, Roseau County. Hayes Lake State Park. About 30 km south-southeast of Roseau, south of County 4. T160N, R38W, Sec. 32. A single 6 × 12 m patch, with an estimated 50 plants, in old-field in sparse grasses on sandy soil under a single mature *Acer negundo.* Associates include *Botrychium minga-*

nense, B. pallidum, B. neolunaria. June 20, 2017. *Malcolm MacFarlane 765* (MIN) 958749 [1305591].

MINNESOTA, Lake of the Woods County. Red Lake Wildlife Management Area, south-southeast of Norris Camp, and south of Hogsback-O'Brien Forest Road. T159N, R35W, Sec. 2. A single 10 × 30 m patch in a homestead site, with an estimated 40 plants, in dense *Bromus inermis* with scattered small *Populus tremuloides.* Associates include *Botrychium minganense, B. neolunaria,* and *B. pallidum.* June 6, 2015, *Malcolm MacFarlane 593* (MIN) 948765[1291656].

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I would like to thank Don Farrar, who examined many specimens and visited all three Minnesota field sites. Welby Smith and Richard Haug gave freely of time and talents on multiple occasions. Thanks also to Bobby Henderson, who tracked phenology at the Chippewa National Forest site and escorted us there on several occasions, and to the Leech Lake Indian Reservation. The folks at Red Lake Wildlife Management Area, Gretchen Mehmel, Charlie Tucker, and Deb Beckel, made us welcome and comfortable over many seasons of field work in accommodations at Norris Camp. Special thanks to Rosemary, for her assistance and patience.

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BOOK REVIEW

Garrett E. Crow and C. Barre Hellquist. 2023. *Aquatic and Wetland Plants of Northeastern North America, Second Edition.* University of Wisconsin Press, Madison. lx + 887 pp., hardback. ISBN 978-0-299-34300-2. $99.95.

The importance of wetlands, both to people and to the environment, is well known. They provide food and habitat for large numbers of plants and animals. They enhance water quality, provide flood and erosion control, maintain stream flows, and provide food for us, among many other things. In addition, they are among the most productive habitats on earth and are important sites for the storage of atmospheric carbon. For all of these reasons, wetlands have long been considered important objects of conservation efforts, particularly given the penchant of humans to destroy them. For those studying wetlands, as well as those involved in conservation or restoration efforts, it is necessary to have available means of accurate, complete, and up-to-date identification of aquatic and wetland plants. In northeastern North America, nothing could be better for this purpose than the second edition of Crow and Hellquist's *Aquatic and Wetland Plants of Northeastern North America.* This is a major updating of the first edition (Crow and Hellquist 2000) that covers the same territory—southeastern Manitoba and Minnesota to Missouri, eastward along the 50th parallel on the north to Newfoundland and Virginia. The southern boundary is adjacent to the range covered by Godfrey and Wooten (1979, 1981) in their corresponding manual for the southeastern United States. The current work treats 1,223 species plus 44 additional infraspecific taxa in 325 genera and 112 families of vascular plants.

A major feature of this volume that greatly enhances its value is the large number of illustrations; nearly all species are illustrated with line drawings taken from a variety of published sources (with permission). The sources and, when known, the names of the artists, are acknowledged in an extensive acknowledgments section at the beginning of the book. The illustrations are large and easy to use. They are well chosen to illustrate both the habit of the plants and critical characters that are necessary for identification. The treatment of each species includes the scientific name, one or more vernacular names, a brief statement of the habitat and distribution of the species, important synonymy, and a numerical reference to the accompanying illustration, which are placed on a page very near the treatment of the species. Infraspecific taxa are similarly treated. Genera are provided with the Latin name, one or more vernacular names, a brief description, useful references, and, for genera with more than one taxon treated in the book, a key to the taxa. There is also a general key to families at the beginning of the book. The keys were rigorously field tested by students taking the several classes in aquatic plants taught by one or the other of the authors or by Ronald L. Stuckey. Generic descriptions are designed to be diagnostic, and, to the extent

possible, keys depend on vegetative characters, which are often of value in identifying aquatic and wetland plants.

The species are arranged in three major groups, Pteridophytes, Gymnosperms, and Angiosperms. The families of angiosperms are further arramged in accordance with the major groups recognized by the Angiosperm Phylogeny Group (APG IV 2016), that is, Primitive Angiosperms, Magnoliids, Monocots, Eudicots, Rosids, and Asterids. Within each such group, the families are arranged in accordance with the Pteridophyte Phylogeny Group (2016) for Pteridophytes, Lu et al. (2014) for Gymnosperms, and APG IV (2016) for Angiosperms. Genera and species are arranged within each major group in the order in which they key out (genera and species are numbered, both in the key and in the individual treatments to make finding them easy).

A valuable introductory chapter on "Nuisance Aquatic Plants of the Northeast" and a glossary, list of references, and index at the back round out this timely and valuable volume.

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BOOK REVIEW

Welby R. Smith. 2023. ***Ferns and Lycophytes of Minnesota: The Complete Guide to Species Identification.*** **Photography by Richard W. Haug. University of Minnesota Press, Minneapolis. xxiv + 321 pp., paperback. ISBN 978-1-5179-1466-0. $39.95.**

This is a worthy successor to three previous guidebooks by Welby Smith on various groups of vascular plants of Minnesota: trees and shrubs (Smith 2008), native orchids (Smith 2012), and sedges and rushes (Smith 2018), the two most recent of which were reviewed in the pages of this journal (Reznicek 2016; Marcum 2019).

As the author notes in the Introduction, this book is not meant to be a monograph, an encyclopedia, or an exhaustive treatise. Rather, it is meant to answer the simple question: "Which plant is that?" To that end, the treatment of each species is kept brief and presented on two facing pages and follows the same format throughout. The left page of each species treatment contains the scientific name and a common name of the species at the top followed by three sections of text: a description of the species, notes on identification, and notes on the natural history of the species. At the upper right of the page is a distribution map showing the outline of the counties of Minnesota and a black dot indicating the location of each specimen in the herbaria examined by the author, primarily the herbarium of the University of Minnesota. The map is also color-shaded indicating the distribution of each of the four major vegetation zones in Minnesota: (i) the eastern broadleaf forest province which occupies the southeastern portion of the state and extending in a narrow band through the central portion of the state; (ii) the Laurentian mixed forest province, which occupies northeastern and north central Minnesota; (iii) the tallgrass aspen parklands province, which constitutes a small area in northwestern Minnesota; and (iv) the prairie parkland province along the western border of the state, broader in the south, but narrowing to the north. A description of each of these zones is provided in the Introduction.

The facing page of each species treatment contains two to five photographs of the species. The photographs, all apparently *in situ*, are at once uniformly excellent and beautiful. They are expertly chosen to show the habitat and general habit of the species as well as particular characteristics that are useful for identification. The principal photographer, Richard Haug, is due a tremendous amount of credit for adding materially to the usefulness of this volume (a small number of photographs are by others, as indicated by the photographer's name beside the photo).

After a brief Introduction, the main part of the book is divided into the eight orders into which the Minnesota taxa fall: Lycopodiales (clubmosses, firmosses, and ground-cedars), Isoetales (quillworts), Selaginellales (spikemosses), Equisitales (horsetails and scouring rushes), Ophioglossales (adders'-tongue ferns),

Osmundales (royal ferns), Salviniales (water ferns), and Polypodiales ("true ferns"), prefaced by a key to the orders. The treatment of each order begins with one or more pages including a discussion of the taxonomy, description, and natural history of the order, a key to Minnesota genera in that order (if more than one), and a facing page with photos on a white background of all or representative genera or other characteristics. In turn, each genus begins with a page or more of discussion, a key to species (if more than one), and a facing page with outline habit photos of each species. All in all, this provides abundant means to help the user identify the Minnesota species. Families are not prominently shown, although the discussion of each genus mentions the family to which it belongs, or, if an order contains only one family, this is mentioned in the discussion of the order.

Three genera that include numerous species in Minnesota are *Equisetum* (nine species and one hybrid in Minnesota), *Botrychium* (14 species), and *Dryopteris* (eight species), which means that this volume will be of particular value to those trying to identify these species in the broader Midwestern region. This is especially true for *Botrychium*, for which this volume may be the only readily available source for the identification of many of the recently described species in this now greatly enlarged genus. As noted in the Acknowedgements, the treatment of this genus follows closely the work of the late Warren H. Wagner, Jr., Donald Farrar, and Rosemary and Malcolm MacFarlane.

The book concludes with a useful glossary, bibliography, and index.

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BOOK REVIEW

Joseph Romm. 2022. *Climate Change: What Everyone Needs to Know. Third Edition*. Oxford University Press, New York, N.Y. xxv + 322 pp., paperback. ISBN 978-0-1976-4713-4. $18.95.

David Ray Griffin. 2015. *Unprecedented: Can Civilization Survive the CO_2 Crisis?* Clarity Press, Inc., Atlanta, Georgia. 515 pp., paperback. ISBN 978-0-9860769-0-9. $34.95.

Mark Maslin. 2021. *Climate Change: A Very Short Introduction. Fourth Edition*. Oxford University Press, New York, N.Y. xxix + 166 pp. ISBN 978-0-19-886786-9. $11.95

There are numerous books for the general reader that explore many individual aspects of climate change: the basic science, description of projected impacts, denialism, adaptation, alternative energy solutions, political and policy solutions, economics. The books under review here, on the other hand, each present an overview of the entire topic.

The book by Joseph Romm is the most recent of these and is a clearly-written and reasonably comprehensive place to start. The author earned a doctorate in physics from the Massachusetts Institute of Technology and has been a student of climate change for several decades. He served as an Assistant Secretary of Energy in the Clinton administration where he oversaw the development and deployment of low-carbon technology. The major topics are covered in six chapters—basic climate science, extreme weather, projected climate impacts, avoiding the worst impacts, climate politics and policies, and the role of clean energy. A final chapter briefly explores the impact of climate change on the individual reader. The text is divided into 97 questions, each concerning a particular issue, and most of these are answered in one to four pages. All are listed in the Table of Contents, which makes it easy for the reader to go immediately to any point of interest. Typical questions are: "What is the greenhouse effect and how does it warm the earth?"; "How does climate change affect wildfires?"; "What kind of droughts can we expect this century?"; and "What is carbon capture and storage (a.k.a carbon sequestration) and what role can it play?" Throughout, Romm relies exclusively on published research and reports of climate scientists or on interviews and correspondence with them for the aspects of the book dealing with the science of climate change and its physical and biological impacts.

The basic science of global warming is treated briefly at the outset. It is important to understand the difference between the terms "global warming" and "climate change." The term "global warming" refers to the increase in the *average* temperature as measured over the entire surface of the earth over a period of

time, for example, one year. Absent global warming, the average global temperature varies by only a small fraction of a degree from year to year, despite much larger local daily and seasonal temperature changes, even of as much as several tens of degrees. In effect, the average global temperature is a measure of the energy in the world's climate system. Thus, increases of even one degree in the average global temperature represents the addition of significant amounts of energy to the system. The term "climate change," on the other hand, refers to the climatological changes caused by the increased energy in the system. Climatological effects of the added energy include more powerful storms, alterations in precipitation patterns, and similar changes, even possibly colder than normal temperatures in some areas for certain periods of time.

The basis of global warming is what is known as the "greenhouse effect": radiation from the sun hits the earth's atmosphere, where one-third is reflected back into space by the atmosphere or the surface of the earth. The land, the oceans, or the ice all absorb the rest. A portion of the absorbed energy is reradiated, primarily as infrared radiation. Certain gases in the atmosphere, called greenhouse gases—especially water vapor, methane (CH_4), and carbon dioxide (CO_2)—are able to trap some of the reradiated energy, which thereby heats the atmosphere and provides warmth for the planet. Greenhouse gases in the atmosphere are necessary to keep the earth at a temperature that is more conducive to life. Without any, the earth would be about 33 degrees Celsius (60 degrees Fahrenheit) colder than it is now. At the beginning of the industrial revolution, the CO_2 level in the atmosphere was about 280 parts per million (ppm). Since then, humanity has poured large amounts of CO_2 into the atmosphere, raising the level to 422 ppm as of July 2023 (NASA 2023). This increase in atmospheric CO_2 has caused the global average temperature to rise by 1.1°C (2.0°F) over the past 200 years, that is, since the beginning of the industrial revolution, most of which has occurred in the last 50 years.

One of the results of global warming is sea-level rise. Sea level has risen several inches since 1900, and, during the past 30 years, has risen ca. 0.3 cm (0.12 inches) per year, which is double the rate of increase during the previous 80 years. The principal contributors to sea-level rise are thermal expansion of the ocean (that is, as the water warms, it expands), which currently accounts for about half of the rise, and loss of ice from glaciers and the ice sheets on Greenland and Antarctica. In the future, however, rise from loss of ice will greatly exceed that from thermal expansion. The complete melting of the Greenland ice sheet would raise the sea level by about 20 feet, and the complete melting of the Antarctic ice sheet by about 200 feet. Even now, research shows that the West Antarctic ice sheet, which is melting from below, is unstable. The ocean is also warming, in recent years quite rapidly, because more than 90% of anthropogenic warming goes into the seas.

Romm notes that substantial evidence from many independent sources supports the overwhelming conclusion of climate scientists that global warming is a settled fact and that it is caused by human activity. It is true that climate has changed in the past throughout earth history, sometimes dramatically. The cause of any event of climate change is some sort of external change, referred to as a climate forcing. Forcings can include changes in radiation from the sun, changes

in the earth's orbit, the release of greenhouse gases into the atmosphere, or volcanic eruptions, which may emit particulate matter that stays in the atmosphere for a period of time and blocks some of the incoming rays from the sun. Historical natural climate change has been much slower than the current anthropogenic change. Although atmospheric levels of CO_2 have in the distant past been much higher than they are currently, the current level is unprecedented in the experience of the human species, but so is the rate of increase. The rapid increase makes it more difficult or even impossible for humans to mitigate climate change or to adapt. Similarly, plants and animals find it difficult to adapt to rapid change and face possible extinction. Furthermore, although there are slow natural processes that reduce the level of CO_2 in the atmosphere, these will be overwhelmed by rapid increases. In addition, amplifying feedbacks can be triggered.

Amplifying feedbacks are processes that introduce additional forcings that reinforce warming. For example, as warming increases, land and sea ice will melt. The darker earth and sea absorb more heat than the white ice, which reflects a greater amount of radiation back into space. Another example is the greater rate of evaporation, which increases the amount of water vapor (another greenhouse gas) in the atmosphere. Or the increased number and severity of forest fires that liberate CO_2 stored in the vegetation. These amplifying feedbacks, among others, increase warming, which in turn induces further feedback and additional warming.

Another factor that must be considered is the level at which tipping points are reached. Tipping points are levels of greenhouse gases that, when they are reached, trigger irreversible changes in the climate. After a tipping point is reached, the climate change will remain irreversible for 1,000 years or more, even if levels of atmospheric greenhouses gases decrease. These irreversible changes may include droughts and continuing sea-level rise caused by the continuing melting of surface ice. Another is the thawing of permafrost in the arctic that will release methane stored in frozen plant material below the surface. Current evidence is that we are getting close to some tipping points, and may have already passed at least one.

More frequent extreme weather events have been a feature of recent years worldwide. These include heat waves that are more frequent, longer-lasting, and more intense; more severe droughts as well as shifting patterns of precipitation; more frequent wildfires that last longer and burn larger areas; and higher and stronger storm surges in coastal areas resulting from hurricanes and other severe storms. One often hears these events referred to as, for example, 500-year droughts, or 1,000-year heat waves. That means that such extremes would previously have occurred only rarely. Now, we are seeing these extremes much more frequently and, in the space of just a few years, with many more new records than previously.

There are well-understood mechanisms that cause the greater frequency of these extreme events. Envision a normal distribution of summer temperatures, with high temperatures and hot summers toward the right side of the distribution and cool summers toward the left side. As average temperatures increase, the frequency of hot summers will also increase, while cool summers, although still occurring from time to time, will happen less often. In that way, even a small in-

crease in average global temperatures will have an outsize impact. The increased evaporation caused by global warming is one factor in creating stronger droughts, especially in already low-rainfall areas, such as the arid areas in the subtropical belts of the world, including the southwestern US. Rainfall patterns are also shifted by higher average temperatures in a way that expands areas subject to drought. They are also exacerbated by higher average temperatures. Global warming often creates high pressure systems that block air circulation, thereby increasing the length of droughts. Longer summers result in drier fuels and less rainfall, which promotes easier ignition, causing more frequent and more devastating wildfires. These in turn release more carbon into the atmosphere, thereby constituting an amplifying feedback. The evidence is very clear that global warming is a major cause of more extreme precipitation and deluges since a warmer atmosphere can hold more moisture. But climate change also alters the jet stream and other weather patterns in a way that causes storm systems to get blocked, thereby releasing more moisture over a greater period of time in a single location. Though it may seem counter-intuitive, global warming also causes increased snowstorms, or greater amounts of snow, in some areas. The reason is that snow is normally formed only in a narrow temperature range just below freezing; colder temperatures prevent the formation of snow. Thus, as warming increases, there will still be periods of colder weather for many decades in many areas. But the average temperatures in a locality will be warmer, which means that that there will be a greater frequency of subfreezing temperatures in the range in which snow formation is optimal.

As with precipitation in general, the greater tendency of atmospheric systems to create blocks upon increased warming brings about record-setting snowfalls or rainfalls. It is evident that rising sea-levels will cause storm surges to be higher, even if the storms causing them are not more intense. But storms will, on average, be more intense with greater global warming, which will increase the severity of storm surges even more, thereby causing greater amounts of damage. Storm surges are the most damaging aspects of hurricanes, which are also becoming more intense. Although they may not be increasing in frequency, a larger proportion of them are in categories 3–5. The warmer temperature, both of the atmosphere and of the ocean surface waters, increases the intensity of hurricanes and also permits them to hold more water, thereby causing greater rainfall and consequent flooding, another dangerous aspect of these storms.

Scientific studies conclude that most of the warming, and the concomitant climate change, that has occurred since the beginning of the industrial revolution, and all of it that has occurred since 1970, is the result of human activity. The primary sources of greenhouse gas from human activity are burning fossil fuels and deforestation. This is strongly supported by many different lines of evidence. First, the warming that is measured tracks exactly the levels of increase in atmospheric CO_2. In fact, minor changes that can be measured in the rate of increase of atmospheric CO_2 can be correlated with emissions, for example, the decrease in emissions right after the Kyoto Protocol went into effect in the early 1990s and again during the oil crisis on 1974 are each mirrored by a slight slowing of the rate of increase of atmospheric CO_2 (Krauss 2021). Second, studies indicate that possible natural causes of warming, such as changes in the earth's

orbit or in solar radiation, would actually have resulted in slight cooling. Third, since carbon exists in more than one isotope, analysis of atmospheric carbon shows that the isotype produced by the burning of fossil fuels is present in the atmosphere in precisely the abundance that would be expected if fossil fuel use is the cause in contrast to the composition of samples of ancient atmospheres taken from preserved ice bubbles buried in polar ice sheets.

Arguably the most important part of Romm's book is a lengthy section describing the impacts that can be expected during the remainder of the twenty-first century under a "business-as-usual" scenario, that is, "no significant action to reduce greenhouse gas emissions trends in the foreseeable future." Very briefly, these impacts can be summarized as (i) very high increase in temperatures, (ii) aridification of many areas, including those with high populations and agricultural areas, creating extensive Dust Bowl regions, including the southwestern US and southern Europe, (iii) extensive loss of biodiversity, both terrestrial and marine, (iv) great increases in extreme weather, (v) food insecurity, making it significantly more difficult to feed the world's increasing population, and (vi) numerous health impacts. Current estimates are that, without mitigation, by the end of the century, global temperatures will reach 4°C (7°F) or more over pre-industrial levels. This would create significant challenges for adaptation. Although there is much uncertainty as to these projections, most of the uncertainty involves even greater warming. A major cause of uncertainty is poor understanding of the sensitivity of climate to feedbacks, such as the melting of ice, increased water vapor, or thawing of the permafrost, which would release carbon (mainly in the form of methane) stored in the frozen tundra. The current path is causing an increase of CO_2 levels in the atmosphere to a much greater extent than the previously predicted 550 ppm. This earlier prediction was based on projections by the Intergovernmental Panel on Climate Change (IPCC), which was established to provide governments with the scientific basis for policy and carried the expectation that its advice would be followed. But that has not happened.

Recent estimates for the range of sea-level rise by 2100 have been 2–6 feet. It now appears that the lower estimate is highly unlikely and that the upper estimate is considerably more than six feet. The estimates of the rate of sea-level rise have also increased, in some cases to as much as one foot per decade after 2050 and two feet per decade after 2100. One major cause for these increased estimates is a greater understanding of the rate of melt of the Greenland and Antarctica ice sheets. This will likely require the displacement of hundreds of millions of people who live near sea shores by the end of the century. It is not merely the submergence of coastal areas that will be a problem, but also the intrusion of saltwater into coastal agricultural areas. Even areas that are not submerged will experience salt water intrusion into subterranean water tables that will make growing crops difficult or impossible. This will also affect the availability of drinking water and water for irrigation and will adversely affect nearby freshwater ecosystems.

Superstorms, such as Hurricane Sandy that devastated coastal New York and New Jersey in 2012, will also become more severe and more frequent. As the atmosphere warms, it can hold more water vapor, which increases precipitation. At

the same time, atmospheric blocking patterns will become more frequent, which will hold storms in place for longer periods. Each degree centigrade of global temperature rise increases the frequency of Hurricane Katrina-level storm surges by three to four times. A two degree rise will increase the frequency by ten times.

By the end of the century, as much as one-third of currently habitable and arable land will be subject to near-permanent drying. This will be much worse than the 1930's Dust Bowl—the drying will be longer-term, often lasting as much as several decades. Large portions of the US, Brazil, Africa, Europe, and other areas will be severely affected by the 2060s. The severity will be exacerbated by the confluence of the two causative factors, extreme heat and decreased precipitation, either one of which alone is sufficient to cause a drought.

Devastating health impacts are in store in a business-as-usual scenario. These include increased mortality caused by longer and stronger heat waves and heat stress, as well as malnutrition arising from decreased availability of food and water. Spending time outside in extreme temperatures, which will become common in many areas, will itself be unhealthy. By 2100, up to three-fourths of the world's population will be exposed to deadly combinations of heat and humidity during parts of the year. Increased warming will also enhance the conditions that foster vectors of infectious diseases; in particular, habitats for carriers of tropical diseases will expand, bringing these diseases to areas of the world where they do not currently exist. Large-scale climate-induced migration of human populations will cause civil unrest, which, among other things, will be a factor causing increased disease. Security problems will limit the availability of food, water, and sanitation, as well as medical services in general. Higher temperatures alone will reduce human productivity, especially for those working outdoors, with concomitant negative economic effects.

One-fourth of the CO_2 that is added to the atmosphere becomes dissolved in the ocean, where it is converted into carbonic acid. This increases the acidity of the oceans. Measurements show that the acidity of the oceans has increased by 30% since the beginning of the industrial revolution, and that rate is increasing. An important result of this is the inability of marine organisms to form shells and skeletons in such animals as corals, mollusks, and some plankton. Plankton is an important base of the marine food chain, and its loss will have deleterious effects on the biodiversity of the ocean. This will also impact the availability of marine-based food for humans. Ocean acidification is a significant tipping point, since it is irreversible within tens of thousands of years.

The current extinction crisis results from numerous causes, among them habitat destruction, overfishing, and overhunting. Climate change will become a major additional factor as warming continues, particularly because the high rate at which warming increases will make it difficult or impossible for many species to adapt. As noted in the previous paragraph, ocean acidification will be a contributing factor, but, in addition, as oceans warm, their ability to hold dissolved oxygen will decrease, thereby creating and expanding dead zones and in general smothering many marine animals. Even for many species that may survive this crisis, genetic diversity will be depleted, damaging their ability to adapt and decreasing their chances of long-term survival.

The ability to feed the people of the world will be another major casualty of

climate change in this century. As already noted, aridification of arable land, salt-water intrusion into coastal areas, and ocean acidification will be significant negative impacts on food production. As food becomes scarcer, it will become more expensive, in many cases significantly so, which will greatly increase poverty and malnourishment throughout large areas of the globe. This fact, along with massive levels of climate-induced migration, will create security threats, including civil unrest and violent conflict. These, in turn, are major factors that can lead to the establishment of authoritarian governments.

Romm explores best case and worst case scenarios for the remainder of the century. The best case would be keeping temperature increase below 2°C (3.6°F). This would require keeping CO_2 levels in the atmosphere below 450 ppm. Since the level is already above 420 ppm and increases at about 2 ppm per year, this would require a very aggressive effort worldwide to cut emissions. A best case scenario would still result in increased extreme weather events, but more calamitous impacts would likely be avoided. In a business-as-usual scenario (that is, no significant efforts to decrease emissions), the IPCC has projected CO_2 concentrations above 900 ppm by 2100, resulting in warming above pre-industrial levels of about 4.2°C (8°F). This projection, however, does not take into account the potential for significant feedbacks, which means that under this scenario, warming would be even greater. It is also true that we do not know precisely at what point irreversible feedbacks will be triggered. In particular, it is not clear whether even a 2°C limit would be enough to prevent the collapse of the West Antarctic ice sheet.

The IPCC's most recent review of scientific literature shows an upper range of business-as-usual results to be warming of 7.8°C (14°F) by 2100. The worst case scenario would involve widespread drought and desertification, mass extinctions both on land and in the sea, large-scale increases in extreme weather events, sea-level rise significantly greater than six feet, all of which pose significant threats to human health, national security, and food availability, can cause severe economic decline and violent conflicts, and would render large areas of the earth's land surface uninhabitable to humans.

It is important to understand that even if emissions are brought to zero, whatever level of warming has been reached by that time will remain for hundreds of years. That is because CO_2 stays in the atmosphere for a long time. In addition, as noted previously, tipping points can trigger irreversible events that will not be stopped even by reducing emissions.

The worst impacts can be avoided, but only by aggressive action. Romm lays out what must be done to keep warming below 2°C. This is the threshold that most climate scientists and governments believe will avoid dangerous impacts. In reaching this goal, it is important to understand that there is a time lag built into the climate system. Even if atmospheric CO_2 levels are stabilized and emissions are at zero, temperatures will still continue rising for a few decades. Certain impacts, such as the melting of ice sheets will also continue, as will sea-level rise. Therefore, it is necessary to reduce emissions of CO_2 dramatically well before the 2°C threshold is reached. If we wait too long, numerous additional irreversible feedbacks will be triggered.

As a practical matter, keeping below the 2°C threshold, which means keeping

atmospheric CO_2 concentrations below 450 ppm, will require immediate action to reduce global greenhouse gas emissions by 50% before 2050 and to continue the decline so that net emissions will reach zero by 2070. Even this may be too little if it turns out that significant feedbacks are triggered earlier than is contemplated in current models.

In a rather short section of Romm's book, he identifies four types of policies that governments use to reduce greenhouse gas emissions: economic, regulatory, technological, and land use policies. The economic category includes policies to increase the price of CO_2 or reduce or subsidize the cost of alternative energy sources. One way of increasing the price of CO_2 is to impose a tax on the emission of greenhouse gases, with two goals: one to select a rate of tax that reflects the social cost of carbon, and the other to increase the cost of emissions in such a way as to disincentivize emissions. The "social cost" of carbon emissions is an estimate of the cost of harm done to society that is not included in the actual cost, which typically reflects only the cost of production plus a profit to the producers and sellers. The goal of subsidizing alternative sources of energy, such as nuclear, solar, or wind, as well as the cost of technological innovation, is to bring their cost down, thereby increasing the use of these sources, which will in turn bring the cost down further. A second economic policy is cap-and-trade or carbon trading. A government agency, such as the EPA, sets an upper limit on emissions for an entire industry. It then issues or sells permits to individual companies. A company is then allowed to produce emissions up to the amount of the permits it has received, but no more. If it produces less, it can sell unused permits on a secondary market similar to a stock exchange. The system works, because the number of permits available each year are gradually reduced, thereby reducing the overall level of emissions. This creates an incentive for long-term technologies and strategies for the reduction of CO_2 emissions. This system has been used in the past successfully to reduce and eventually phase out leaded gasoline and sulfur dioxide, which caused acid rain.

Regulatory policies to increase the use of alternative energy sources or to reduce the use of fossil fuels include such things as fuel economy standards for vehicles, promoting the use of electric vehicles, efficiency standards for appliances, and similar policies. Technological policies include those that promote research into and deployment of clean energy sources, including lowering their cost and improving their performance. Such policies can also improve the efficiency and cost of appliances and other energy uses. Land use policies include lowering the rate of deforestation or the planting of trees.

Romm discusses the use of geoengineering to reduce or halt global warming. Two principal categories of geoengineering have been proposed: removing carbon from the atmosphere and albedo modification. There are serious problems with the deployment of both of these. Carbon removal is deemed to be relatively safe, but the technology does not exist that would permit scaling up to the level needed to remove sufficient carbon from the atmosphere to make a meaningful difference. It would also be prohibitively expensive. More serious, however, are problems with storage of carbon once it is removed (referred to in the literature as carbon sequestration). It requires massive compression of the removed carbon to a liquid form that can then be injected into underground storage places, typi-

cally depleted oil, gas, or coal reservoirs. Because this would have to be done at a rate that is at least equal to the annual production of these fossil fuels, the time frame is prohibitive. Furthermore, leakage is a major problem—since effective storage would have to last for thousands of years, even a very small rate of leakage, such as less than 1% per year, would render this useless. There is also the possibility that earthquakes could be triggered by the injection of massive amounts of liquefied CO_2 into these repositories, which, among other things, could result in the release of the stored carbon.

Albedo is the reflectivity of solar radiation by the earth. The idea is that by increasing this reflectivity—albedo modification—warming would be reduced because the earth would then absorb less heat. The principal means for doing so involves injecting massive amounts of aerosols into the stratosphere, which would block a portion of incoming sunlight, similar to the way that volcanic eruptions produce particles that, once entered into the atmosphere, cause cooling. There is, however, no way at present of predicting secondary effects that could be significantly deleterious. Increased reflectivity could disrupt food production, alter precipitation patterns causing droughts or excess rainfall, or further deplete the ozone layer. And there is no way of testing this method of albedo modification short of full-scale execution. But perhaps the most serious problem is that it would do nothing to reduce CO_2 emissions; if warming is reduced by albedo modification, there would be a strong temptation not to reduce the use of fossil fuels. Even though the direct effects of warming might be avoided, there are other effects, such as ocean acidification and its effects on terrestrial ecosystems, that would continue unabated. Furthermore, since aerosols would have very short lifetimes in the atmosphere, massive injections would have to continue at frequent intervals long into the future, perhaps indefinitely. If for any reason this process were to halt or be reduced (and it is impossible to predict with certainty what might cause this—wars, economic emergencies, technological problems), the earth would immediately be subject to the severe impacts of far greater levels of CO_2 in the atmosphere than at present.

It should be clear, therefore, that in order to keep warming below 2°C, steep declines in carbon emissions will be necessary. There must be a 50% reduction by 2050, and that pace must continue until we reach net-zero emissions by 2100. Since the largest component of human source emissions of CO_2—78% in the period since 1970—has been fossil fuel and industrial emissions, deep cuts in fossil fuel use are essential for meeting this goal.

Increasing energy efficiency is one of the most important strategies. It is defined by Romm as "reducing the energy consumption of our products and services, while maintain or improving their performance." He gives several reasons why it is important: (i) it is the largest resource; (ii) it is by far the least expensive strategy; (iii) it is by far the fastest strategy to deploy; and (iv) it is "renewable"—it never runs out. Examples of energy efficiency include such actions as insulating a home, increasing the fuel efficiency of vehicles, replacing incandescent lighting with LED bulbs, using sensors to time the use of artificial lights, or designing building to make use of more daylight, among many other examples. Studies have shown that aggressive use of efficiency strategies will substantially lower the cost of climate action. In the US, two types of regulatory policies re-

garding energy efficiency have succeeded in decoupling economic growth from energy demand—that is, increasing gross domestic product (GDP) increased decreasing while energy consumption. The first of these policies is the requirement that utilities deploy a specific level of efficiency practices. The second involves regulations that decouple a utility's revenues from the amount of electricity that is sold.

More importantly, however, achieving sufficient reduction in emissions requires the largescale use of alternative, or carbon-free, sources of energy. Since nuclear power currently (as of 2015) provides the largest share of low-carbon energy, both in the US and worldwide, many people advocate greater use of this source. There are problems with this, however. New nuclear plants are extremely expensive, currently costing as much as $10 billion for one new plant. This is because they must be built to withstand virtually any conceivable risk, since disasters or human error can be catastrophic. For this reason, very few new plants have been built in the last few decades. The disaster at Fukushima in Japan has been a principal reason for the slowdown. Furthermore, the rapidly decreasing costs of natural gas and renewable energy sources, as well as advances in energy efficiency, have rendered half of the US nuclear plants unprofitable. Another problem is that the operation of a nuclear plant requires massive amounts of water—typically 35–65 million liters per day—which will be problematic in a world with increasing droughts.

Natural gas is increasingly used as an energy source, because it is less carbon intensive and burns more efficiently than the other fossil fuels. It is, nevertheless, a carbon-based fuel and will have to be phased out rather quickly if we are to keep global warming below 2°C. There are two additional challenges with using natural gas as a bridge source of energy. Because it is relatively inexpensive, it can delay the conversion to more efficient energy sources. Furthermore, it releases methane (CH_4), rather than CO_2, which is 86 times as potent a greenhouse gas as CO_2, although it remains in the atmosphere for a much shorter time period. Finally, if it used as substitute for nuclear or other renewable energy sources, as it is to some extent, it would be counterproductive as a strategy to reduce greenhouse gas emissions.

The most promising sources of alternative energy are solar power and wind power. There are two principal types of solar energy production: photovoltaic (PV), in which sunlight is converted directly into electricity, and concentrated solar thermal power (CSP), in which electricity is produced from the heat from focused sunlight. In recent decades, the cost of solar power has decreased precipitously so that now it competes favorably with electricity from the power grid, and manufacturing, sales, and installations of solar power facilities have similarly increased. Commitments by countries worldwide, including China and the European Union, to significantly expand the use of renewable energy insure that the cost will continue to drop. The energy required to manufacture a PV system is also decreasing, which makes it more likely that solar power will be a major facture in sustaining a global economy while emissions of greenhouse gases decline. Although PV sources of solar power constitute by far the largest share of solar energy, CSP has important characteristics that may well make it more valuable in the future. These include the fact that the heat produced by this

method can be stored much more efficiently and inexpensively than electricity, which means that it can be used to provide energy during high demand times when sunlight is not at its peak. Current projections are that both forms of solar power combined can produce as much as 27% of the world's electricity needs by 2050, provided appropriate policies are in place and technology continues on its current path.

Current projections are that wind power can produce as much as 18% of the world's electricity by 2050. The cost of wind power has decreased significantly in recent years, partly as a result of improvements in the aerodynamics of the blades used on wind turbines. This has enabled effective wind turbines to operate in areas that are less windy than was previously necessary. Also, these improvements have permitted the generation of wind power over a wider range of wind speeds and directions. Cost reductions have been particularly steep with respect to offshore wind farms. These are especially desirable for two additional reasons: they can be sited close to population centers where other sources of alternative energy are less available, and offshore winds are generally stronger and more consistent than over land.

Biomass has also been suggested as a source of renewable energy. However, it is far less efficient than most other forms, and, more seriously, it requires the use of vast amounts of arable land that will be needed for food production. This will be especially critical as the climate warms and drought-stricken areas increase. Other forms of renewable energy that are considered include hydropower and geothermal power. Hydropower, primarily from hydroelectric dams, currently produces about 16% of the world's electricity. Even if power from this source is doubled, it will still produce only about 20% of the world's electricity as energy demand increases in future decades. Geothermal power is provided primarily by two types of facilities. Large geothermal plants extract heat directly from underground hot water or steam to operate turbines to produce electricity. These plants provide large proportions of the electrical needs in certain places, such as Iceland, parts of Central America, Kenya, and the Philippines. Despite this, large plants for geothermal power will likely be a minor player in the production of carbon-free energy. A second form of geothermal power production uses small pumps that use underground heat directly to heat buildings and power certain industrial processes. These systems are highly efficient and can be used in any climate. They will play a useful, but minor, role in future energy production.

Romm emphasizes that the transportation sector will require major attention in the effort to replace carbon-based fuels with alternative energy sources. In the US, for example, transportation has accounted for 69% of the increase in CO_2 emissions since 1990. Vehicles operating on carbon-free fuels are confronted with several market challenges, such as high cost and the difficulties of refueling, and therefore large-scale deployment will require government intervention. However, since they are not currently cost-effective, even government intervention may be problematical. Romm identifies several barriers to the acceptance and success of alternative-fuel vehicles, including high initial cost, limited range, safety concerns, high cost of fuel, limited availability of fuel stations, and competition as a result of improvements in the fuel efficiency of conventional

vehicles. The limited availability of fuel stations underscores a conundrum—the reluctance to invest in a wide network of such stations before compatible vehicles are available accompanied by a reluctance to manufacture, sell, or purchase such vehicles before sufficient fueling stations are available. Hybrid vehicles avoid many of these problems and serve as a useful bridge to fully alternative-fueled vehicles. Despite these obstacles, it is nevertheless necessary to cease the use of carbon-based fuels in the very near future, and therefore extensive research and development is this area is ongoing. Indeed, the deployment of electric vehicles has been increasing in recent years, and is expected to continue to do so, especially as prices decline. The cost of batteries, which has been a significant component of the greatly inflated price of electric vehicles, was originally extremely high, but has recently experienced significant decreases.

In a final chapter, Romm discusses how climate change will affect each of us as individuals and our families. Some of the most significant social and personal impacts are ones that may not have been foreseen. Therefore, it will be important to understand climate change impacts and the transition to clean energy. Not only those living on the coast, or contemplating doing so, or investing in coastal properties, but all of us must come to realize that the value of most coastal properties will crash as sea-levels rise. This will have a significant impact on the national and global economy. It is not possible to predict when such a crash is likely to occur, but preparation will be essential. Future changes in habitability, precipitation patterns, and other weather changes will also impact our decisions of where to live, where to work, or where to invest. Younger people starting to give thought to a career may also wish to consider what careers will be needed as we, as a society, confront the challenges brought on by climate change. We must also all consider ways to reduce our own carbon footprints. Even though actions by an individual will have insignificant effect, and since no individual action will be effective without governmental and international action, collective efforts by all will be helpful and necessary in confronting the challenges we face from climate change. In a penultimate section of this chapter, Romm provides responses to several popular climate science myths in a discussion of how we can talk about climate change to those who do not accept the scientific evidence for its reality. Finally, in a hopeful mood, Romm poses the final question of the book: "Do we still have time to preserve a livable climate?" The answer he gives is "for now, yes." It is easy to despair if we focus only on the latest science and the inadequacy of our political leadership. But there are many hopeful signs. Although it will take much more than current efforts to keep warming below 2°C, the nations of the world are making stronger commitments, clean energy technology and deployment is ramping up, and more and more people are making efforts at education and action. And, even if we somehow fail to meet the 2°C threshold, it will still be necessary to continue action thereafter to keep warming as close to that level as possible and not fall into despair and denial.

David Ray Griffin's *Unprecedented* covers much of the same ground as Joseph Romm, often in greater detail. But in addition to the areas of overlap, which I will not belabor here, he covers some important additional areas. The author, who died in 2022, was Professor of Philosophy of Religion and Theology,

Emeritus, at Claremont School of Theology and Claremont Graduate University. The basic science of global warming, which is very briefly discussed by Romm, is not covered at all by Griffin, but is taken for granted. As an illuminating exercise, the author sets out three different levels of response by the US in the Introduction, referred to as Plans A, B, and C. He then examines the various types of impact under each of the three levels. Plan A is the world's political leaders simply continuing as they have, that is, business as usual. Plan B is taking aggressive action to keep global warming below the 2°C target, although, citing climate scientist James Hansen for the declaration that 2°C of warming would be a disaster, Griffin concludes that this plan should have an even lower target. Plan C, referred to as wait and see, contemplates that political leaders will delay taking any immediate action, waiting to see if the scientists' predictions are correct and not wanting to cut fossil fuel use for fear of its adverse effect on the global economy. Under this plan, leaders would begin to take action only when there is unambiguous evidence that anthropogenic climate change will have serious deleterious effects. There are serious problems with Plan C, however. One is that once CO_2 enters the atmosphere, it remains for at least 1,000 years, so that even if carbon emissions are halted entirely, conditions will not return in any meaningful amount of time to what they were earlier. In fact, it would be worse, because of the lag time of about 30 years between the emission of CO_2 and the effects caused by the new level of CO_2 in the atmosphere. By the time conditions have reached the point at which Plan C advocates realize that action is needed, considerably worse conditions will have already been irreversibly baked into the mix.

In four chapters devoted to extreme weather, Griffin covers much the same ground as Romm, but makes some useful observations. First, he notes that extreme weather events are best referred to as "climate disruptions," because they are threats that disrupt human life in unprecedented ways. When such extreme weather occurs, the question often arises whether that particular storm, heat wave, or other event is attributable to climate change. Because of the natural variability in weather, many have taken the position that no individual event can be attributed to climate change. However, because extreme events have become increasingly more frequent, we can conclude with high confidence that most such events would not have occurred in the absence of climate change.

Griffin notes that in the absence of global warming, normal variability in weather would statistically produce roughly equal numbers of record low temperatures as record high temperatures. But that is not what has been happening; the evidence is that the number of record highs is statistically greater than the number of record lows.

Under Plan A, the impacts will be severe. By century's end, the average global temperature will reach 6°C higher than preindustrial temperatures, that is 5° higher than it is currently, and there will be no stopping point thereafter. Daily temperatures will commonly reach as much as 122°F in the southern, central, and western US, and even higher in other places. By the next century, areas where half of the world's population now lives will become uninhabitable. A third of the land surface of the world will be under a permanent drought, including much of the US, southern Europe, Africa, Australia, and other areas. There

will be significantly more powerful and more frequent storms, deluges, and hurricanes. Sea-levels will rise one foot by 2050, and 4–6 feet, or more, by 2100. It will continue to rise thereafter, ordinarily by 6–12 inches per decade, but the melting of the Greenland and West Antarctica ice sheets will add 39 feet. This will inundate areas that now support populations of 650 million people and include much prime agricultural land. Coastal cities, such as Miami, New York, Seattle, San Francisco, and many others in the US and around the world will be uninhabitable. The loss of mountain glaciers and snowpack means that, in addition to drought and extreme heat, the southwestern US will lack sufficient fresh water to support its present population, at least in late spring and summer. Worldwide, billions of people will be without adequate fresh water and be unable to survive. Agriculture will become impossible in places with extreme heat and drought. Destructive storms, rains, and flooding will adversely affect the availability of wheat, rice, and many other crops, as will salinization of agricultural areas due to sea rise. Ocean acidification will deplete stocks of seafood. It will therefore become difficult or impossible to provide sufficient food to much of the world's population.

Plan B is taking immediate and aggressive steps to cease carbon emissions. However, even if emissions were to stop tomorrow, conditions would still worsen for a while, because of the 30-year lag that is already built into the system. Among these effects are that extreme weather events will continue to worsen, but we will avoid catastrophic temperatures, storms, and sea-level rise. The global average temperature will continue to rise, perhaps to 1.5 or 2°C above preindustrial levels. There will be warmer weather than today, but although unpleasant, it will not be intolerable for most people. Droughts and wildfires will continue to increase, but the affected areas will not become unlivable, and storm damage, while increasing, will nevertheless be limited. Perhaps the worst effects will come from continuing sea-rise, again already built into the system, and there will be much distress, but large-scale migration inland will be avoided. It will be important to take aggressive steps to protect coastal cities and military installations. Many of these steps are described in detail in Goodell (2017), which will be the subject of a future review. Long-term expensive investments in coastal properties will not be wise and must be discouraged, but that may be difficult to explain to many people. In this regard, Griffin describes the recent law in North Carolina, for example, that requires state agencies to base all assumptions about future sea-level rise solely on linear projections from historical data, which will seriously underestimate the amount of rise in the near future. There will continue to be loss of fresh water in many parts of the world, but not so much that would cause the collapse of civilization or massive numbers of deaths. Food shortages will continue to worsen, but the severe conditions that would ensue from a business as usual scenario will be avoided. Since even the immediate cessation of emissions will not magically return the world to what we experienced even a few decades ago, or even keep conditions at the level they have currently reached, it will be necessary to accompany efforts to cease emissions and replace fossil fuels with renewable energy sources with adaptation strategies. Many of these will be discussed in future reviews.

The wait-and-see scenario, Plan C, will result in impacts much closer to those

under Plan A than Plan B. To begin with, it will result in warming of at least 4°C above pre-industrial levels by 2100. Even if Plan C efforts succeed in keeping warming within that goal, there will still be irreversible impacts, such as decreased rainfall in dry areas, expanded areas of desertification and dust-bowl conditions that will not be reversible within any meaningful time frame. Even the eventual cessation of emissions will likely not avoid runaway warming as the result of tipping points that will be triggered before that level is reached. As a result, this plan will not be significantly different from Plan A. It will not be possible to avoid the melting of the major ice sheets, and the consequent sea-level rise will be catastrophic. Even a little warming will cause severe disruptions in the availability of fresh water for large portions of the earth's population. Similarly, food availability will also be severely impacted. Thus, a wait-and-see scenario will not avoid dire consequences.

As the worsening climate makes certain areas either uninhabitable or very difficult to live in, the number of so-called "climate refugees" will increase. International law does not recognize that term, and persons leaving areas because they are forced out by climate-influenced changes are not covered under the *Geneva Convention Relating to the Status of Refugees*, which limits its protection to people leaving an area because of their fear of state-led persecution. Nevertheless, climate refugees will become an increasingly prominent phenomenon in the coming years and decades. Although climate refugees will be escaping many different climate-induced emergencies, Griffin focuses his discussion on sea-level rise, discussing in detail a few areas of particular importance. The Carteret Islands are a small group northeast of Papua New Guinea. The entire population of about 2,600 is being forced to move, because their low-lying homeland is threatened by rising seas. Among other things, their home-grown food sources, such as breadfruit, bananas, and coconuts, can no longer be well-supported. The so-called seasonal "king tides" are becoming more dangerous, and inundation is creating breeding grounds for mosquitos carrying malaria. Griffin notes the especial cruelty of their situation, because they have not contributed at all to the problem—they have no roads, no vehicles, and no airplanes, and they have little use for electricity.

The president of the Maldives, a nation consisting of an archipelago in the Indian Ocean, warned that the nation faced disappearance due to rising seas and moved to support an international coalition to lower the levels of CO_2 in the atmosphere to 350 ppm. He was very much involved in negotiations at the 2009 climate conference in Copenhagen and in subsequent conferences, and did what he could at home to make his nation carbon neutral. Unfortunately, he was removed from office by a coup, which, as Griffin notes, illustrates the tendency of many politicians to take their own political contests more seriously than the threats facing their homelands.

The Sundarbans are in the delta of the Ganges River and constitute the largest mangrove forest in the world and is highly biodiverse. They are situated so as to protect low-lying coastal communities from the effects of large storm surges. However, over 185,000 acres, including some entire islands, have been submerged in the last 30 years. Under the current trajectory, 75% of the area will be destroyed in the next 40–50 years, giving rise to the migration of large numbers

of people—the population of the delta area is about 4 million. Already, more than 200 people leave the area each day, mostly moving to Calcutta, which is already overcrowded.

The nearby nation of Bangladesh is one of the countries most threated by sea-level rise, which will require the relocation of as much as 25–35 million people, which, in turn, will greatly increase the level of poverty. Since the remainder of Bangladesh is already very densely populated, this will create pressure on other countries to accept refugees. This pattern will be repeated in many places throughout the world. It will also underscore the need for further development of international law and organizations to expand the formal definition of refugee to include those escaping devastating effects climate deterioration.

There are national security consequences to climate change. Among these is the creation of climate refugees. Another is war, which may arise from conflicts over arable or habitable land, or a breakdown in food systems, or from other impacts, and may affect vast populations. Even if the rest of government has paid too little attention to climate change, the military and the intelligence community has been acutely aware of security threats occasioned by climate change. In fact, in the US, the Pentagon has long considered these threats as sitting at the forefront of its concerns and has sponsored numerous studies. It applies the concept of "threat multiplier" to climate change effects. That is, even if many wars are not initially, or even primarily, about climate, climate change does factor into them and exacerbates the conflict. The perspective of the military on climate change has been treated in much detail by Klare (2019).

Though small or local ecosystems may collapse from time to time from a variety of causes, scientists are becoming aware of the possibility of large-scale, or even global, ecosystem collapse as a consequence of global warming, particularly under a Plan A scenario. Perhaps the most obvious such event would be the collapse of the oceanic ecosystem resulting from ocean acidification, which would destroy coral reefs and prevent the formation of the calcium skeletons or exoskeletons of many marine animals, but most pertinently of foraminifera, which are the base of many oceanic food chains. Attention has also focused on the possibility of more extensive collapse on land. A 2004 study (Thomas et al. 2004) found that under a business as usual scenario, 15–37 percent of land animal and plant species would be committed to extinction by 2050. Griffin notes that a 2007 study concluded that the plankton, edible fish, bees, and topsoil, all of them essential to human survival, are in severe danger and their loss must be averted. A comparative study of historical extinction rates with those of today concluded that species are now disappearing at a rate 1,000 times that of the past and that we are facing a major extinction crisis comparable to the end of Cretaceous extinction event that spelled the end of the dinosaurs and large numbers of other species (Pimm et al. 2014).

An important study discussed by Griffin attempts to recognize planetary boundaries that must be observed to prevent global ecosystem collapse (Rockström et al. 2009). The idea is that as the earth transitions from the Holocene (the geological epoch that began following the latest glacial era, about 10,000 years ago) to the Anthropocene (a proposed geological epoch that began at the dawn of the industrial revolution or later in recognition of the substantial human im-

pact on the earth's geology and biosphere, including climate change), many of the conditions that permit the maintenance of the global ecosystem are being altered beyond the bounds that held sway during the Holocene. The authors ask what the non-negotiable global preconditions are that we need to respect in order to avoid catastrophic environmental change on a planetary scale. They refer to the preconditions as thresholds—a concept that is similar to the tipping points we have already discussed with respect to irreversible changes brought on by climate change. Transgressing one or more of these thresholds could lead to an abrupt change in the global ecosystem. Since we have no precise knowledge of these thresholds, in particular when, or under what conditions, they would be triggered, the authors call for study of the dynamics of these thresholds and the associated feedbacks on a continental and global scale. They suggest that we agree on a set of boundaries within which we can expect to operate safely. At one point it was assumed that a 4°C rise in global temperatures would provide safety for global ecosystems, but most scientists later came to believe that no more than a 2°C rise will guarantee safety. However, Rockström et al. (2009) proposed that a safe boundary would be an increase of no more than 1.5°C. They recognize nine planetary boundaries, of which three have already been passed. These include atmospheric CO_2 concentration and loss of biodiversity. They urge that we do what can be done to repair or mitigate the boundaries that have been passed and also to ensure that no further boundaries are passed.

Griffin agrees with numerous scientists that the release of methane from permafrost in the Arctic poses the greatest threat of collapse of the global ecosystem. Permafrost is the expanse of soils in the Arctic that has been frozen since the most recent glacial period. It contains vast amounts of carbon from dead animals and plants, primarily in the form of methane. It is estimated that the carbon in the permafrost constitutes half of all the carbon stored in the earth's soils. If it were all to be released, it would constitute four or five times all the carbon that has been released by human activity since 1850. The concern is heightened because the Arctic is warming twice as fast as the rest of the planet, which makes thawing of the permafrost, and the consequent release of methane, even more likely. This is particularly so, since most of the carbon is in the top three meters of the permafrost. If the permafrost is on dry land, the carbon will be broken down by oxygen-breathing bacteria and released as CO_2, whereas if it is below a wetland, it will be released as methane, which is a far more potent greenhouse gas than CO_2. It was once thought that the release of methane from permafrost was a minor problem that would take place only in the distant future. But there is now strong evidence that the release is happening now. In recent years, the shallow waters off the Arctic coast of eastern Siberia on what is known as the Arctic shelf is saturated with methane, which was later shown to be arising from underwater permafrost. If business as usual continues, the release of even a portion of the methane stored in the shelf is released, that could trigger substantial abrupt warming. Because of the increased warming, the methane release will become self-sustaining as a positive feedback loop, leading to runaway warming and ecological collapse. In 2013, it was discovered that permafrost in the Antarctic region is also subject to warming and release of carbon.

Efforts to deal with the reality of climate change have been hampered by a

vigorous denial movement. Therefore, in order to understand and act on climate change, it is necessary to understand and engage with the denialism. The book *Climate Change* by Joseph Romm briefly refers to denialism, whereas Griffin devotes an entire chapter to this topic. Since I am planning a full review on this topic in a later issue, I will not go into much detail here, but suffice it to say that any understanding of denialism must begin with a perusal of *Merchants of Doubt* by Naomi Oreskes and Eric Conway (2010), which is also discussed at some length by Griffin. Very briefly, Oreskes and Conway point out that climate change denial is nothing new, and they describe how the denialist campaign is not only very similar to previous anti-science denial campaigns over the past 60 some years, but have involved the very same individuals and the institutions they created to foster those campaigns. These include the denial by the tobacco industry and its supporters against the strongly supported evidence that nicotine causes cancer, and shortly afterwards that secondhand smoke is also dangerous; the denial by polluting industries that certain sulfur-based pollutants cause acid rain, which caused devastating losses among trees, fish, and other organisms; the denial by the chemical industry that chlorofluorocarbons released by spray cans, refrigerators, and air conditioners were damaging the ozone in the stratosphere, which protects us from damaging ultraviolet light from the sun; the denial by pesticide manufacturers about the danger caused by DDT, as was thoroughly exposed by Rachel Carson in her book *Silent Spring*. Beginning several decades ago, the fossil fuel industry, despite the knowledge that they had developed internally about the reality of anthropogenic climate change and its cause, employed the same people and institutions to carry out a pervasive program of disinformation and denial and of influencing politicians. These methods include using front organizations, hiring a handful of scientists whose conclusions are not in line with those of the vast majority of the scientific community to make authoritative-sounding pronouncements, and placing denialist articles in various publications, while at the same time concealing the source of support for these individuals and organizations from within the fossil fuel industry.

Concomitant with the denial campaign, the efforts to deal with climate change have also been hampered by the failure of the media, especially in the US, to report vigorously and accurately on this issue, and Griffin devotes another chapter to this topic. The principal reason this is a problem is that, as the prominent climate scientist James Hansen has indicated, getting government to act boldly requires public pressure, which, in turn, requires a fully informed populace. But, as a result of this failure by the media, there is not only a large gap between the understanding of climate change by scientists on the one hand and by the public at large on the other, but there is also a remarkable inconsistency in their respective views. To put this in perspective, Griffin cites a parable devised by the journalist Eric Pooley, in which we suppose that scientists had discovered a meteor rapidly moving toward the earth that would strike later this century with dire consequences and that we had only ten years to divert or destroy the meteor. The news media would be completely on top of the story and would cover it exhaustively so that it became the story of the century. Of course, unlike the case with climate change, there is no powerful industry or other interest that would benefit from obscuring the truth about the meteor. Climate change is the

meteor that threatens civilization, but in this real-world case the media coverage is tepid at best.

Griffin posits several aspects of the failure of the media to report fully in climate change. One is the practice of false balance. To be sure, balanced reporting is a hallmark of good reporting. But that requires that two or more sides have at least arguably equally valid arguments, or, if not equal, at least of sufficient significance to be recognized. However, when there really is only one well-supported and valid side to a story, it is a disservice to the consumers of the news to act as if opposing viewpoints have equally valid reasons to be heard, and more of a disservice if the two sides are reported without any commentary distinguishing between the validity of the one and the lack of support for the other. Another aspect is the felt need by the media to report on conflicts, even when there is none. By holding up both sides of the so-called climate "debate" (a misnomer if there ever was one), the media feeds the hunger for provocative stories and controversy. The third aspect is the powerful presence of fossil fuel advertisers who would threaten to withdraw their lucrative business if the media reported fairly and accurately on a topic that they would rather not see treated in that fashion. Griffin notes that news coverage of climate topics has actually been decreasing over the last several years, and that it is more likely to cover supposed scandals, such as the "climategate" stories than the substance of international conferences. Weather reports on television often cover extreme weather events without any mention of climate change. Finally, there are the explicit denialist outlets, among which Griffin mentions *Fox News*, the *Wall Street Journal*, the cable channel CNBC, and certain opinion columnists in the *Washington Post* and other newspapers.

A third obstacle to effective and aggressive action to protect us against climate change that Griffin explores in some depth is political failure. Along with many others, Griffin recognizes climate change as "the defining challenge of our time." "However," he further notes, "the political world has not risen to this challenge." Scientists have been sounding the alarm publicly and in many ways to alert governments to the catastrophe that will follow upon continued business as usual, but this has had little effect. This is not because political leaders have been misinformed. Griffin recounts the numerous reports made for and at the behest of government, international conferences, international agreements, and many other forms of communication, in which the facts have been clearly presented. So, why has the political world failed to take meaningful action? One reason, perhaps, is simply that humans, including politicians, are often foolish, in this area as in so many others. More importantly, however, Griffin believes that politicians do not fully appreciate the difference between science and politics. The latter is often seen as the "art of the possible," doing what can be done in an environment where compromise and negotiation are the main tools, unlike science, which does not compromise to reach its conclusions. It is too easy to see action, even on this "defining challenge," as politics as usual. It is all too easy to fail to grasp the stakes. Another important factor can be laid to the common human weaknesses of fear, greed, and self-interest. There is no lack of knowledge about the problem, nor are cost-effective solutions lacking. What is lacking is the necessary political will. The short-sightedness can be exemplified by an

Asian foreign minister attending the Copenhagen Conference on climate change in 2009 who averred that he was not there to save the world, but to protect his country's national interest. This attitude has surely been repeated many times. Self-interest also applies to large fossil fuel corporations that have known of the danger for decades, but nevertheless act in their own financial interest. Governments, including legislative bodies, are populated by many who are friendly to the fossil fuel industry, whether because of their receipt of massive donations or because their own districts are home to these facilities.

Given these failures, it is important to examine the moral challenge facing us as a society, which Griffin characterizes as "unprecedented." He quotes Bill McKibben (2012) as also recognizing this as "the greatest challenge humans have ever faced." Griffin notes that, despite the variety of religious and philosophical traditions in the world, a basic ethic is recognized by virtually all traditions, which is some version of the Golden Rule: Do not do to others what you would not have done to you. There exist also nearly universal sets of negative injunctions against such basic acts as murder, lying, stealing, and so forth. In this spirit, Griffin has fashioned what he calls the ten climate commandments, which forbid such actions as depriving people of clean air or clean water, destroying their soil, ruining their seas, forcing them to migrate, and so forth. He notes that fossil fuel corporations have violated all of these, and that governments have failed to protect people from these violations. There is also a strong tradition of basic human rights, an important example being the *Universal Declaration of Human Rights* that was approved by the UN General Assembly in 1948. The ideas, however, go back at least to classical times, and more recently to the French *Declaration of the Rights of Man*. These basic rights should form the bedrock principles on which climate action must rest. An ancillary principle is that of intergenerational justice, whereby we owe duties not only to our contemporaries, but also to generations that will follow us. The principle has been enunciated by many sources, including the *Constitution of the Iroquois Nations*, Thomas Jefferson, and many climate scientists and activists. In the context of climate change, an important consideration is the duty owed by rich nations, which have been most responsible for creating the problem, to the poorer nations of the world.

Because solving the problems created by climate change involves much more than just scientific or technological expertise, economics is necessarily involved. Griffin gives a substantially more detailed discussion than the brief sections of Joseph Romm's book, but, since this topic will be covered in a future review, I will not go further into it here.

The final section of *Unprecedented* discusses alternative sources of energy and the abolition of fossil fuels, as well as the means of achieving these goals. This is not materially different from Romm's discussion of these topics, albeit presented in greater depth, and so there is no need to cover that section here.

Climate Change by Mark Maslin is one of over 700 titles in the *Very Short Introduction* series published by Oxford University Press. Each volume presents, usually in less than 200 pages, a concise, but authoritative, treatment of a topic for the general reader by an expert in the field. They are meant to be balanced and complete (at least within their small compass). The author is a professor of

Earth System Science at University College London in the UK. It covers much the same ground as do Romm and Griffin, but more concisely. But it has some features of its own that make it a useful complement to the books by Romm and Griffin. Unlike either of the other volumes, Maslin's book is liberally supplied with charts and graphs that help make the facts of the science and their impacts more palpable. The basic science is treated somewhat more fully than in either Romm or Griffin. After a brief explanation of the greenhouse effect, Maslin describes the variations in atmospheric CO_2 over the past 800,000 years, which covers eight cycles of advances and retreats of glaciation. By drilling deeply into the Greenland and Antarctic ice sheets, scientists are able to recover air bubbles that became trapped when the ice was first laid down. By analyzing the air in these bubbles, the composition of the air and the average temperature can be determined. Paired graphs show how the temperature tracks the variation in CO_2 concentration. This varies between ca. 180 ppm and ca. 280 ppm throughout this entire period until the very end, where it suddenly increases to more than 400 ppm at the present day. The concentration of atmospheric CO_2 has been measured daily since 1958 at an observatory at the top of Mauna Loa in Hawaii, which is at an elevation of about 4,000 feet. Maslin reproduces a graph showing the results of these measurements. There is an annual variation of a few parts per million that reflects the uptake of CO_2 by plants, which is highest in the northern hemisphere spring, which includes the greatest expanse of land on the globe. This then increases in the fall. But this minor annual variation is a mere blip in the overall virtually monotonic increase in concentration from ca. 316 ppm in 1958 to over 420 ppm today.

Another chart shows the amount of CO_2 emissions annually by nation or region—China, India, the European Union, the US, and the rest of the world—since 1960. Although currently the largest emitter among nations is China, the US has emitted the most in the aggregate since 1960. These results are provided by the IPCC, which was created in 1988 by the United National Environmental Panel and the World Meteorological Organization. The purpose of the IPCC is to make periodic assessments of the state of knowledge about the science of climate change, its physical, biological and social impacts, and strategies to alleviate climate change and its impacts. The assessments are prepared by some 500 experts from 120 countries and are reviewed by thousands of others before they are released. Among other things, these assessments provide governments with information that is useful in evaluating risks and in formulating responses to the climate crisis. The experts involved in drafting the reports are nominated by governments, international organizations, and relevant non-governmental organizations (NGOs).

The IPCC reports reveal that the principal source of atmospheric CO_2 is the burning of fossil fuels. Emissions are not evenly distributed among nations. The vast majority has historically been produced by the developed nations of the world. The next largest source is from land-use changes, mainly deforestation for agriculture, urbanization, or other uses. Humans have contributed about half a trillion tons of carbon to the atmosphere since the beginning of the industrial revolution. About half has stayed there, a quarter has gone into the oceans, and another quarter into the terrestrial biosphere. But the concern is that as the ocean warms, it will be able to absorb less carbon, and as deforestation and agriculture

both grow, the land will also absorb less carbon. The result of both of these processes is that atmospheric concentrations will grow even more quickly than they otherwise would for a given level of emissions.

Maslin also covers a couple other topics in greater detail than either Romm or Griffin. One of these is the history of scientific knowledge about climate change and the response by the emerging environmental movement. Several scientists in the mid-1800s, such as Eunice Newton Foote, John Tyndall, and Joseph Fourier, made the first investigations into the greenhouse gas nature of CO_2. These early investigations were followed up by the Swedish chemist, Svante Arrhenius, who made the first calculations of how much the earth's temperature would vary depending with changes in atmospheric CO_2 concentration. He correctly predicted that the burning of fossil fuels would be sufficient to cause warming. In 1938, the engineer Guy Stewart Callendar gathered temperature records from the previous 50 years from stations around the world and was able to demonstrate that warming was indeed occurring. His continued investigations and publications over the next couple of decades encouraged other scientists to expand those studies. Substantial improvements in technology during World War II allowed Charles Keeling to make more accurate measurements of atmospheric CO_2, and he instituted the daily measurements that have been made ever since 1958 atop Mauna Loa in Hawaii. The nearly monotonic increases are presented in a graph popularly known as the Keeling curve. Despite these scientific advances, acceptance of the reality of global warming was slow to be recognized. One reason for this was a slight decrease in global mean temperatures between the 1940s and 1970s, leading some to predict a new ice age. However, increasing knowledge, both of current conditions and of past climates, indicated that this was extremely unlikely. By the 1980s, sufficient evidence had accrued to demonstrate to a substantial degree of certitude that the climate was indeed warming and that the rate of warming was increasing. An additional factor was the lack of environmental awareness. The establishment of a global environmental movement, at least partially in response to the work of Rachel Carson in the 1960s, began to bring an awareness of global warming to a wider public.

Along with the scientific advances and the growing social awareness has been attention to climate change by some economists. A particularly significant contribution was made by the British economist, Nicholas Stern, who was commissioned by the British government to prepare a report that has become known as the *Stern Review*. This 700-page report recognized the serious danger imposed by climate change and advocated aggressive and immediate action. It concluded that the cost of taking such action now is affordable and would be substantially less than waiting or going slow. Prominent among other economists is William Nordhaus, who was awarded the 2018 Nobel Memorial Prize in Economic Sciences for his work on the economics of climate change. While he recognizing the necessity of action, he thought, at least at first, that 4°C of warming would be acceptable and counseled less aggressive action. Many economists felt that aggressive action now would be too costly. Among the major differences among economists is establishing a proper price to be placed on carbon that would sufficiently discourage its use. A future review will look into these issues in more detail.

Another useful aspect of Maslin's book is his discussion of climate modelling to estimate future changes in the climate and their impacts. To predict future climates, it is necessary to use comprehensive three-dimensional models that include all parts of the climate system and subject them to mathematical analysis based on physical laws. The substantial improvement in models and their accuracy over the last four decades is based on our increased knowledge of the climate system and gigantic leaps in available computer power. The major uncertainty in modelling is not from the science—that is, the physics, biology, and chemistry—but from the difficulty in estimating future emissions of greenhouse gases, which depends on so many things, such as the economy, personal lifestyles, political changes, technological changes, and much more. Nevertheless, computer models have been invaluable in predicting varying outcomes based on different scenarios of future actions by government and industry with respect to climate change. These are presented in some detail in Maslin's discussion.

For those wishing a reasonably quick, but still comprehensive, overview of the subject, Maslin will do admirably. It is very clearly written and provides an excellent overview that may be sufficient in itself for some, and for others it will serve well as an introduction before going into greater depth in other books. Joseph Romm provides a more comprehensive, but still easily digestible, overview that is factual and that covers the major topics in an objective manner. Griffin presents an even fuller treatment of many of the topics, and considers others that are barely touched on by Romm and Maslin. As befits a specialist in the philosophy of religion and theology, he provides a much more thorough moral perspective than either of the other authors. This is underscored by his repetition after each discussion of the differing consequences of following the three plans, Plan A, Plan B, or Plan C, with the phrase: "The only moral choice is Plan B"—that is, immediate aggressive action.

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ANNOUNCEMENT

REVIEWERS FOR RECENT ISSUES

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